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ANTICIPATORY AND INHIBITORY CHARACTERISTICS OF DELAYED CONDITIONED REACTIONS [1,2]

BY ST. CLAIR A. SWITZER

Miami University

The establishment of delayed and trace conditioned responses in man has been reported by Krasnogorski (**11**), Leonow (**12**), and Steckle (**22**). The Krasnogorski data on a delayed conditioned movement response in one child are fragmentary and somewhat inconclusive. Leonow's study of trace conditioning in four children ranging in age from five months to six years has been summarized elsewhere (**19**). Short trace conditioned galvanic skin reactions were obtained by Steckle in six adult human subjects.

It appears, therefore, that while considerable evidence is available concerning the nature of delayed and trace CR's in infra-human organisms (**18, 20**), very few researches on these types of reaction have been made with adult humans as subjects. The need for such studies has become more insistent since the publication of Lepley's interesting hypothesis (**13**) regarding the relationship between trace and delayed CR's and the remote excitatory tendencies of Ebbinghaus

[1] From the Institute of Human Relations, Yale University. The investigation was directed by Professor Clark L. Hull, to whom the writer is indebted for many helpful suggestions.

[2] The second in a series of studies presented to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in psychology, 1934. The first study appeared elsewhere (**23**).

(**4**, **6**). If it should turn out that the long latent period of these reactions is actually charged with inhibitory [3] properties ('inhibition of delay') as the reflexologists claim, it should be possible to deduce a large number of the phenomena of human learning from Lepley's hypothesis. And of far greater importance is the fact that such deductions could be put to experimental test in the laboratory. Considerable unpublished evidence [4] has been accumulated which tends to support Lepley's position, but the final outcome of his hypothesis must await the experimental analysis of the complex characteristics of delayed conditioned reactions in humans. The present experiment was designed to investigate a few of these characteristics.

It may be noted that Pavlov's account of the development of inhibition of delay in dogs contains certain inconsistencies which obscure the problem somewhat. In one connection (**18**, 89) he asserts that the delayed reaction first appears near the point of reënforcement and shifts forward toward the commencement of the conditioned stimulus and finally settles at an intermediate position between these points. Elsewhere (**18**, 235) he states that the latent period gradually lengthens out, moving in a direction opposite to that noted above, until the anticipatory reaction disappears altogether and the conditioned response takes place at the precise point of original reënforcement.

Apparatus

The general experimental situation and essential apparatus have been described in another connection (**23**). In addition to the mechanisms for recording finger retraction and the galvanic skin response (GSR), a Verdin pneumograph communicating with a Becker metal-diaphragm air tambour was added in the present experiment for the registration of respiratory changes. Head phones in circuit with an A.-C. transformer furnished a constant hum which effectively masked ordinary auditory cues.

---

[3] The much-debated term "inhibition" is used throughout this paper in the strictly behavioristic sense either of a measurable decrement in response or an increase in the latency of response. Nothing is implied regarding the neurophysiological mechanisms underlying the phenomenon (or phenomena) herein considered.

[4] Some of which was presented by Professor Clark L. Hull to the Psychology Seminar of Clark University on May 3, 1933, in a paper entitled, "The Delayed Conditioned Reflex and Serial Learning."

The conditioned stimulus was a dim light produced by a screened 6 v. flashlight bulb mounted approximately 2 feet in front of the subject in one panel of the black hood within which the subject was seated. The primary stimulus was a tetanizing faradic current of 1.2 seconds duration delivered to the subject's right index finger. A loud buzzer of sufficient intensity to be heard above the A.-C. hum was mounted on a metal resonator and served as the disinhibitor. The room was darkened throughout each experimental session.

Subjects and Procedure

Pavlov found it impracticable to establish delayed conditioned responses without first establishing the corresponding simultaneous response (**18**, 89). This method was used by the writer. Ten simultaneous light-shock stimulations preceded the delayed series.

In the delayed light-shock combinations, the duration of the visual stimulus was 21 seconds. The onset of the electrotactual stimulus occurred at the end of the 16th second of stimulation by the light, and the light was present for 3.8 seconds following the termination of the shock. This arrangement was designed to control, in part, any tendency to react to the cessation of the visual stimulus. With five subjects (Nos. XI–XV) the light and shock were terminated together at the end of 17.2 seconds. The reactions of this group appeared similar in all respects to those obtained with the extended visual stimulation. To prevent temporal conditioning, the intervals between successive combinations were varied at random from 39 seconds to 3 minutes with all subjects.

Twenty-seven subjects in all were tested in the main investigation. Five of these were returned for measurements of extent of spontaneous recovery after periods varying from 7 to 17 days.

Of the twenty-seven subjects originally tested, twenty were put through the two-day procedure outlined below. Nine of this group of twenty were used in a supplementary experiment after an interval of two weeks had elapsed. One of the original twenty-seven was dismissed at the end of the first day of training because, after the first three simultaneous reënforcements, he invariably removed his finger from the key as soon as the light appeared, thus thwarting the purpose of the experiment.[5] Six others were rejected at the end of the first ten simultaneous light-shock combinations, four because of excess spontaneous variability of the galvanic skin response[6] and two because of absence of the GSR. This factor of selection should not be overlooked in any attempt to evaluate the significance of the obtained data. It is the belief of the writer that the outcome would not have been significantly different if it had been possible to measure and include the GSR's of these rejected subjects,[7] but this is conjecture and must be weighted as such.

Each of the twenty subjects retained was put through an experimental period of approximately 1.5 hours duration on two successive days, as follows:

---

[5] The GSR underwent experimental extinction while finger retraction continued. The relationship between symbolism and the permanence of certain types of conditioned responses has been suggested in other studies (**8**, **23**).

[6] It is probably significant that this increased spontaneous variability of the GSR was most pronounced during the excessively hot weather of the month of June (**2**, **3**).

[7] From the results of another study in these laboratories it is evident that additional resistance in the circuit might have corrected this difficulty.

OUTLINE OF MAIN EXPERIMENT

(20 Subjects—Table 1)

First Day

2 successive presentations of light alone for 21 seconds.
10 successive presentations of *simultaneous* light-shock.
10 successive presentations of *delayed* light—shock.
1 presentation of light alone.
5 successive presentations of *delayed* light—shock.

Second Day

2 successive presentations of light alone for 21 seconds.
10 successive presentations of *delayed* light—shock.
Sufficient *unreënforced* presentations of 21-second light to extinguish the galvanic skin response.
1 presentation of buzzer for 1 second.
2 successive presentations of light alone for 21 seconds.

(Interval of 3 to 5 minutes of rest.)

1 presentation of light for 21 seconds.

The five subjects who were retested for spontaneous recovery after 7 to 17 days were presented with the following stimuli:

OUTLINE OF SPONTANEOUS RECOVERY TEST[8]

(5 Subjects—Nos. III, IV, VI, VII, VIII, of Table 1)

Sufficient successive *unreënforced* presentations of the 21-second light to extinguish the galvanic skin response.

In the main experiment the effect of the disinhibitory buzzer on the latency of the galvanic skin response to subsequent visual stimulation was complicated by the process of experimental extinction. Or in Pavlovian terminology, the 'inhibition of delay' was supposedly influenced by 'extinctive inhibition.' In order to observe the effect of disinhibition upon the latency of the delayed GSR when experimental extinction was ruled out, nine subjects of the main group

[8] It will be noted that each of the 5 subjects received one reënforcement at the end of the original extinction series. It is possible that this may have been sufficient to distort the true picture of recovery.

were put through the following program two weeks after completion of the principal study:

OUTLINE OF SUPPLEMENTARY EXPERIMENT
(9 Subjects—Table 3)

2 successive presentations of 21-second light.
8 successive presentations of *delayed* light—shock.
1 presentation of buzzer alone for 1 second.
2 successive presentations of 21-second light
(Interval of 2.5 to 4.5 minutes of rest.)
1 presentation of 21-second light.

RESULTS AND DISCUSSION

I. The Galvanic Skin Response

An inspection of Table 1 (and Figs. 1 and 2) reveals three distinct characteristics which appeared in the delayed conditioned responses secured under the conditions of this experiment:

First.—The latency of the anticipatory GSR to the visual stimulus progressively increased from a mean of approximately 5 seconds during the first 4 delayed light-shock presentations (following 10 simultaneous L-S stimulations) to a mean of approximately 10 seconds at the end of the training period. The mean latency appeared to remain fairly stable at this point. We might express this result by taking portions from the contradictory statements of Pavlov (*supra*) and combining them, thus: "As time goes on the latent period lengthens out" (**18**, 235), "and finally settles at a definite intermediate position between the commencement of the conditioned stimulus and its reënforcement" (**18**, 89).

Second.—A rest period of 24 hours causes the anticipatory reaction to move forward to, or very close to, its original position. In other words, such an interval reduces the latency of response to the visual stimulus.

Third.—A disinhibitor in the form of a loud buzzer causes an immediate moving forward, or decrease in latency, comparable to that resulting from a 24-hour rest period. This disinhibitory effect upon the latency of the delayed condi-

TABLE 1

SUMMARY OF AVERAGE LATENCIES IN SECONDS OF GALVANIC SKIN RESPONSE TO VISUAL (CONDITIONED DELAY) STIMULUS FOR TWENTY SUBJECTS AT VARIOUS STAGES OF TRAINING, EXTINCTION, DISINHIBITION, AND SPONTANEOUS RECOVERY

All subjects received ten simultaneous light-shock stimulations prior to first delayed light-shock presentation.

Subjects	1	2	3	4	5*	6	7	8*	9*		10*	11	12*	13*
	Trials 1–4 Training Series	Trials 5–8 Training Series	Trials 9–12 Training Series	Trials 13–16 Training Series	Trials 1–2 after 24 Hours	Trials 3–7 2d Day Training	Trials 8–12 2d Day Training	Trials 1–5 Extinction Series	Trials 6–10 Extinction Series	Buzzer	Trials 1–2 after Disinhibition	Trial after 3 to 5 Minute Interval	Spontaneous Recovery after 7 to 17 Days (5 Subjects)	
													Trials 1–4	Trials 5–8
I.....	5.0	6.3	5.0	8.5	—	13.8	13.0	9.4	14.0	Mean latency of GSR to buzzer = 4.3 sec.	6.5	16		
II.....	7.0	6.3	11.5	5.0	—	13.6	14.6	12.6	—		6.5	12		
III.....	3.3	4.5	7.3	14.0	—	10.4	7.0	4.8	5.8		4.5	15	4.5	6.5
IV.....	2.5	4.8	3.5	3.8	3.5	7.6	6.8	8.6	12.3		11.0	16	5.5	8.3
V.....	9.5	9.5	14.5	7.0	3.5	10.6	12.8	8.7	—		7.0	16		
VI.....	8.0	7.0	11.8	7.0	3.0	6.4	7.2	9.0	9.2		5.5	10	5.25	8.7
VII.....	4.8	4.5	4.5	5.3	5.5	6.4	5.2	4.8	6.8		5.0	16	3.3	9.0
VIII.....	4.8	8.0	7.8	9.3	6.0	6.2	6.8	7.8	11.2		3.5	16	8.5	10.5
IX.....	4.0	7.0	8.3	12.3	3.0	6.8	6.2	9.0	5.0		2.5	9		
X.....	7.8	6.0	5.0	7.3	8.5	5.4	8.6	10.3	—		5.0	16		
XI.....	4.0	6.8	9.3	12.0	4.0	7.6	7.6	7.4	7.2		3.0	13		
XII.....	5.8	5.3	5.0	7.0	6.0	9.4	10.6	9.6	—		4.5	10		
XIII.....	3.8	6.8	6.0	10.0	3.0	7.0	8.2	11.0	—		5.0	15*		
XIV.....	3.0	3.0	3.0	3.0	4.0	4.8	7.4	7.6	10.0		3.5	11*		
XV.....	2.3	6.3	8.3	7.8	5.0	6.8	13.4	12.8	16.0		5.0	16*		
XVI.....	4.3	7.5	10.5	12.5	6.0	7.6	9.2	11.0	13.5		4.5	11*		
XVII.....	5.5	10.0	11.0	9.3	3.5	8.4	11.0	12.2	12.3		6.0	7*		
XVIII.....	7.5	11.5	12.0	13.8	6.5	14.0	16.0	15.7	—		6.5	16*		
XIX.....	3.8	7.0	8.0	8.8	11.5	12.0	11.6	13.2	10.0		7.5	15*		
XX.....	5.0	10.8	11.8	15.0	6.0	9.5	14.0	10.6	12.2		5.5	9*		
Total.....	101.7	138.9	164.1	178.7	88.5†	174.3	197.2	196.1	145.5		108.0	265.0	27.05	43.0
Mean.....	5.09	6.95	8.21	8.94	—	8.72	9.86	9.81	10.39		5.4	13.25	5.41	8.6
				8.89†	5.21†									
P.E.$_M$				.556†	.346†			.397			.253			
Diff.			3.68						4.41					
P.E.$_{Diff.}$			.61						.41					
Critical ratio			6.0						10.7					

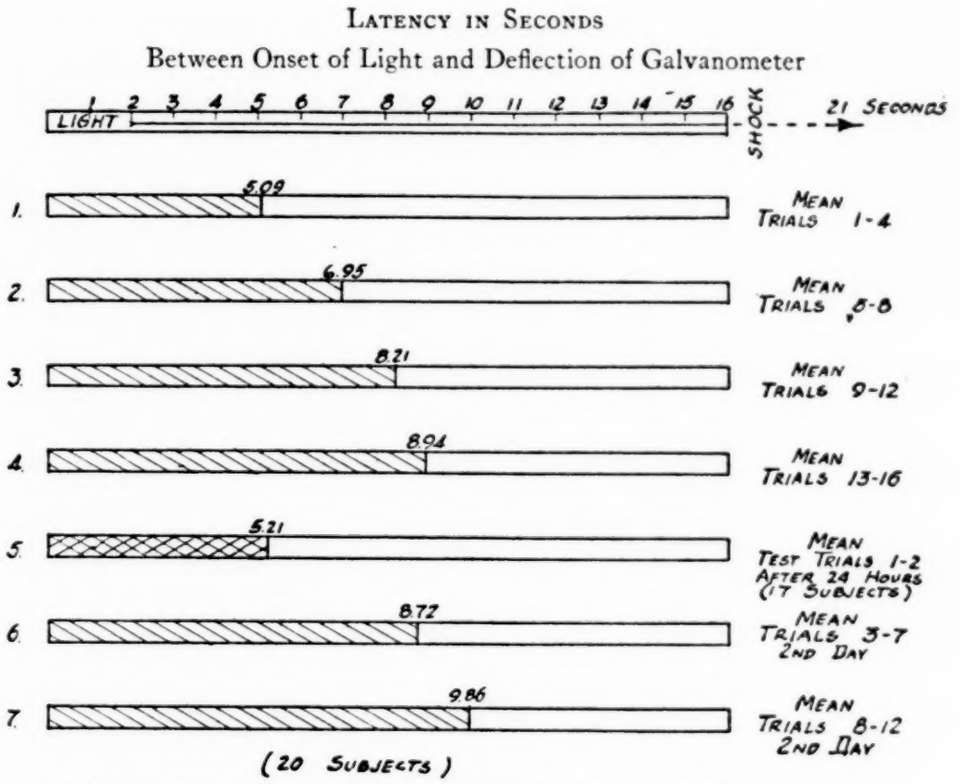

LATENCY IN SECONDS
Between Onset of Light and Deflection of Galvanometer
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
LIGHT
SHOCK
21 SECONDS
1. 5.09 MEAN TRIALS 1-4
2. 6.95 MEAN TRIALS 5-8
3. 8.21 MEAN TRIALS 9-12
4. 8.94 MEAN TRIALS 13-16
5. 5.21 MEAN TEST TRIALS 1-2 AFTER 24 HOURS (17 SUBJECTS)
6. 8.72 MEAN TRIALS 3-7 2ND DAY
7. 9.86 MEAN TRIALS 8-12 2ND DAY
(20 SUBJECTS)

FIG. 1. Graphic representation of first 7 columns of data in Table 1.

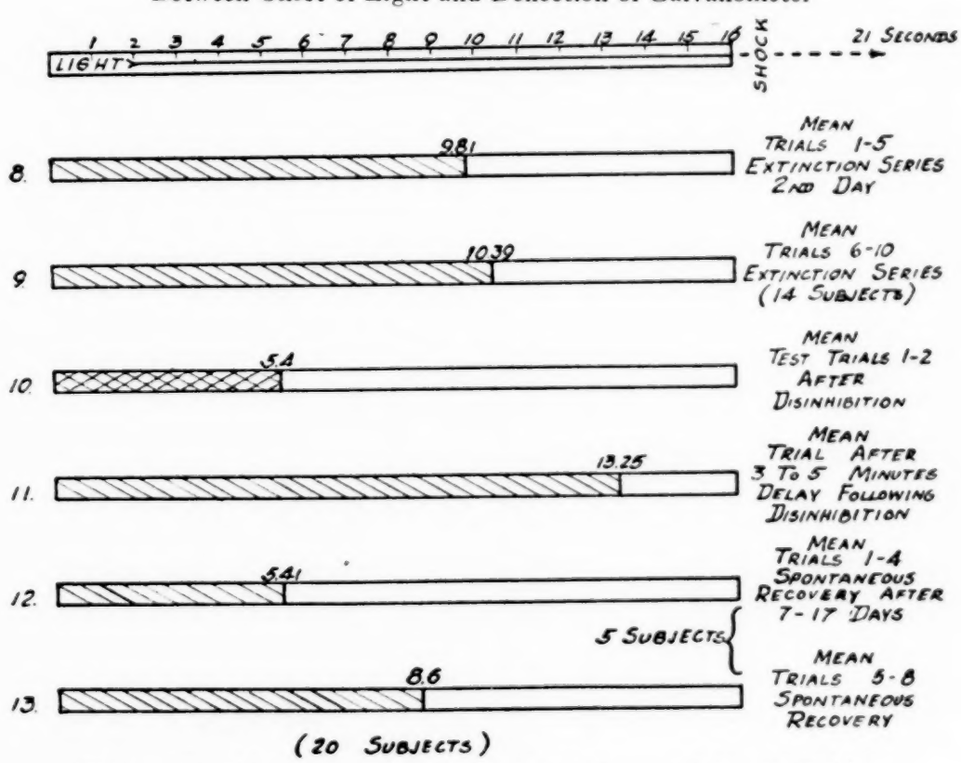

LATENCY IN SECONDS
Between Onset of Light and Deflection of Galvanometer
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
LIGHT
SHOCK
21 SECONDS
8. 9.81 MEAN TRIALS 1-5 EXTINCTION SERIES 2ND DAY
9. 10.39 MEAN TRIALS 6-10 EXTINCTION SERIES (14 SUBJECTS)
10. 5.4 MEAN TEST TRIALS 1-2 AFTER DISINHIBITION
11. 13.25 MEAN TRIAL AFTER 3 TO 5 MINUTES DELAY FOLLOWING DISINHIBITION
12. 5.41 MEAN TRIALS 1-4 SPONTANEOUS RECOVERY AFTER 7-17 DAYS
5 SUBJECTS
13. 8.6 MEAN TRIALS 5-8 SPONTANEOUS RECOVERY
(20 SUBJECTS)

FIG. 2. Graphic representation of last six columns of data in Table 1.

TABLE 2

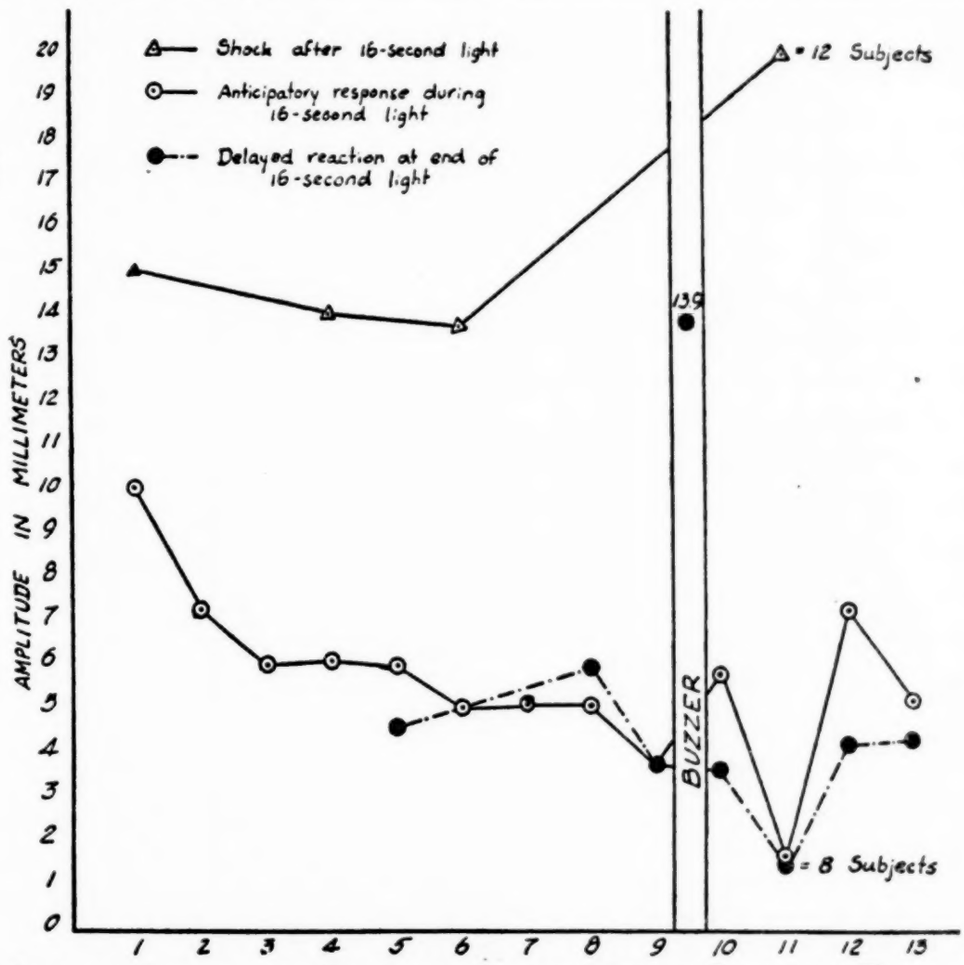
SUMMARY OF MEAN AMPLITUDES OF ANTICIPATORY AND DELAYED CONDITIONED GSR'S OF TWENTY SUBJECTS TO THE VISUAL (CONDITIONED) STIMULUS, AND OF THEIR UNCONDITIONED RESPONSES TO THE AUDITORY (DISINHIBITORY) AND ELECTRO-TACTUAL (REËNFORCING) STIMULI AT VARIOUS STAGES IN THE EXPERIMENTAL PROCEDURE CORRESPONDING TO THE THIRTEEN COLUMNS OF TABLE 1

(Millimeter units.)

	1	2	3	4	5	6	7	8	9		10	11	12	13
Mean amplitude of anticipatory reactions to light	10.8	7.28	6.03	6.13	6.0	5.10	5.10	5.20	3.80	Buzzer	5.80	1.70	7.35	8.60
Mean amplitude of delayed CR (end of 16th second)					4.7			6.0	3.8		3.7	1.5	4.3	4.38
Mean amplitude of GSR to disinhibitory buzzer										13.9		(8 subjects)		
Mean amplitude of GSR to reënforcing shock	15.03			14.08		13.78						20.1 (12 subjects)		

tioned response appears to be much the same whether the buzzer is introduced during training (Column 6, Table 3) [9] or upon completion of experimental extinction (Column 10, Table 1).

In addition to the above points, it may be noted that in some cases the amplitude of the anticipatory response changes in a direction opposite to that of the latency (See Table 2 and


Shock after 16-second light
Anticipatory response during 16-second light
Delayed reaction at end of 16-second light
Δ = 12 Subjects
= 8 Subjects
AMPLITUDE IN MILLIMETERS
BUZZER
139
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
1 2 3 4 5 6 7 8 9 10 11 12 13

STAGES IN EXPERIMENTAL PROCEDURE CORRESPONDING TO COLUMNS OF TABLE 1.

FIG. 3. Showing mean amplitude of galvanic skin response (20 subjects) to the various stimuli at successive stages in the experimental program (see Table 2).

Figure 3), but in other cases this change does not occur (Supplementary Experiment). That these amplitude changes

[9] The average amplitude of the anticipatory reaction of these 9 subjects on the first test following the buzzer was 25 percent greater under the conditions represented in Table 1 than under those represented in the Supplementary Experiment (Table 3). This suggests that in the latter case the buzzer may have exercised a dual effect: (1) as external inhibitor of the delayed conditioned reaction (amplitude), and (2) as disinhibitor (latency).

TABLE 3

SUMMARY OF AVERAGE LATENCIES IN SECONDS OF GALVANIC SKIN RESPONSE TO THE VISUAL STIMULUS FOR THE NINE SUBJECTS OF THE SUPPLEMENTARY EXPERIMENT

Subjects	1 Light Alone 2 Trials	2 Light-Shock Trials 1–2	3 Light-Shock Trials 3–4	4 Light-Shock Trials 5–6	5 Light-Shock Trials 7–8	Disinhibitory buzzer	6 Light Alone 2 Trials	2.5 to 4.5 minutes interval	7 Light Alone 1 Trial
IV	5.5	6.5	6.5	11.0	15.0		6.5		25
VI	4.0	2.5	4.0	7.0	10.0		2.0		9
VII	4.5	4.5	6.5	6.0	9.0		2.5		21
VIII	2.0	3.0	6.5	8.0	9.0		4.5		20
IX	3.5	3.0	3.5	6.0	6.5		4.0		16
X	5.5	3.5	4.0	7.5	7.0		3.0		18
XI	4.5	5.0	3.0	4.5	7.0		3.5		10
XII	3.5	3.0	3.5	7.0	12.0		3.5		11
XIII	5.0	6.0	7.5	6.0	9.5		4.0		10
Total	38.0	37.0	45.0	63.0	85.0		33.5		140
Mean	4.22	4.11	5.0	7.0	9.44		3.72		15.55
$P.E._M$					.546		.257		1.36
Diff.						5.72		11.83	
$P.E._{Diff.}$						1.435		3.244	
$\frac{Diff.}{P.E._{Diff.}}$						3.99		3.65	

may not be attributed to 'the fatigability of the GSR' is indicated by the fact that the extent of the galvanic skin response to the shock shows little or no diminution after the first few trials.

It is also worthy of note that the mean latency of the anticipatory response remains fairly stable throughout the period of experimental extinction of the GSR. (Columns 8 and 9, Table 1 and Fig. 2.)

The apparent stabilization of the latency around the 10th second in the present study should be interpreted with some caution as it is quite probable that this latency would increase still further with additional training until the organism achieved a functional minimum of anticipation. This 'approximation and correction' form of adjustment has been observed in different types of behavior patterns ranging from those involved in the ocular pursuit experiment of Dodge in which subjects showed a tendency to anticipate the pendular movement of an object across the field of vision (**1**), to those reported by Lumley (**14**, **15**, **16**), and Mitchell (**17**), in studies of anticipatory tendencies in serial and maze learning. The extent to which the mechanisms underlying these various patterns of behavior are related is a question which must await further experimental investigation and theoretical interpretation.

The question naturally arose as to what part the initial simultaneous pairings of light and shock played in producing the anticipatory reactions to light during the delay series. This was answered partially by a study of the formation of *trace* conditioned responses in 4 subjects, in which a 16-second interval between the conditioned and original stimuli was used throughout. In this case no preliminary training was given with the simultaneous light-shock combination. After the first 2 trace presentations the responses exhibited the same type of anticipation and gradual increase in latency reported above. The reactions, however, were quite weak and the latencies extremely variable at the end of the sixth experimental day. The conclusion drawn was that the anticipatory reaction occurs at first near the beginning of the period of

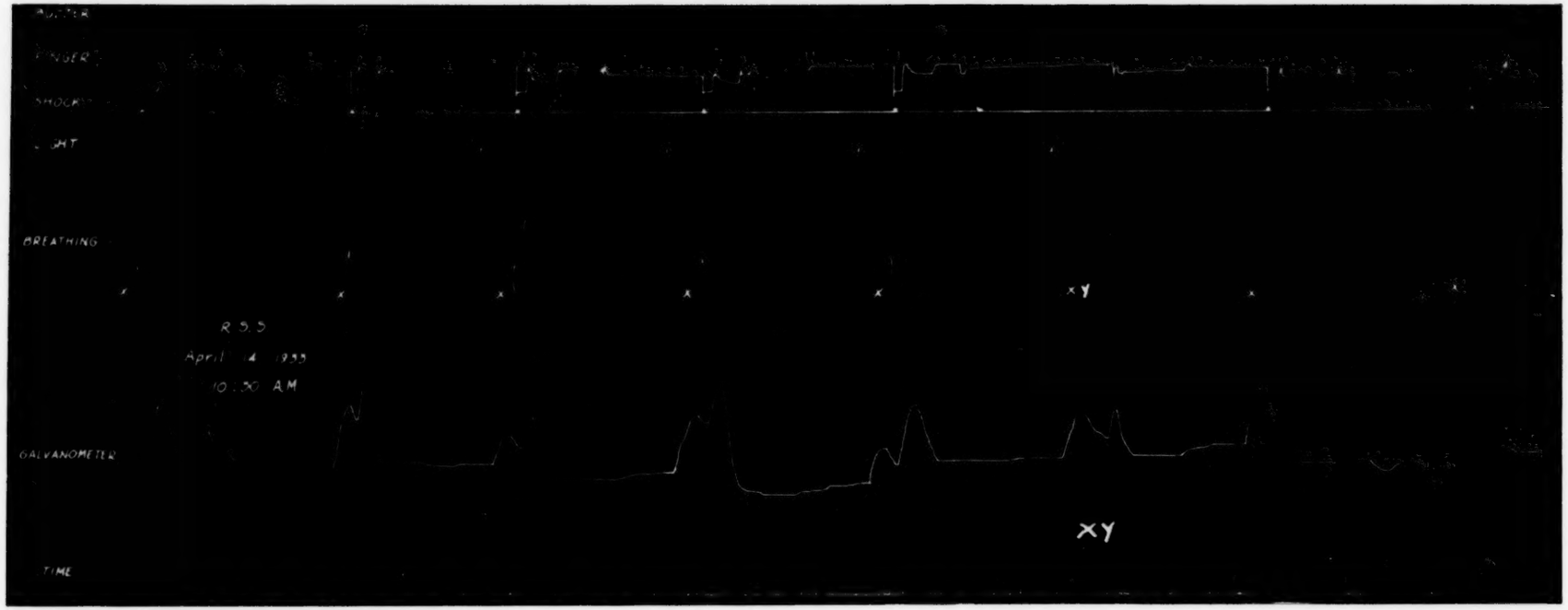


FIG. 4. Sample record showing decrement in breathing during period of delay. Points marked with an 'x' indicate decrements in amplitude of the breathing response during time that conditioned stimulus was present. Point 'XY' is a delayed conditioned response (no reënforcement with shock) which occurred after 10 delayed light shock presentations.

delay and gradually moves toward the point of reënforcement, no matter what technique is used in setting up the delayed reaction.

Hull has pointed out a dilemma of the conditioned defense reaction (**10**) which appears to be resolved in some measure by these data. Column 12 in Tables 1 and 2 shows that the anticipatory reaction moves forward and increases in strength after an interval of 7 to 17 days following complete experimental extinction. This suggests that the biological efficacy of anticipation is not entirely lost when the reënforcing stimulus disappears.

The delayed conditioned GSR's evoked after the 16th second of visual stimulation were of three fairly distinct types, the first two of which appeared most often and with approximately equal frequency while the third occurred but rarely:

1. A secondary deflection superimposed upon the anticipatory reaction and continuing in the same direction.
2. A secondary reaction in the direction opposite to that of the anticipatory reaction.
3. A secondary reaction beginning at approximately the same base line and taking the same direction as the anticipatory reaction.

II. Respiration

Table 4 and Fig. 5 show the effect of the period of delay upon respiration. A fairly marked decrease in volume of respiration, as measured by the Hull oscillometer (**9**), was evidenced during the first 16 seconds of visual stimulation.

The respiratory reactions in the portion of the record reproduced as Fig. 4 show a marked resemblance to those obtained in the auditory discrimination studies of Wever with the cat (**26**), and Upton (**24**) and Horton (**7**) with the guinea pig. Wever's conditioned stimulus, which was presented for an interval of five seconds, produced a characteristic 'flutter response' or smoothing of the respiratory curve after 90 tone-shock presentations. Horton's conditioned stimulus lasted for ten seconds and produced a decrease in both rate and amplitude of respiration after the 130th to 200th trial.

TABLE 4

SUMMARY IN OSCILLOMETER UNITS OF AVERAGE VOLUME OF BREATHING OF TWENTY SUBJECTS AT FIVE SUCCESSIVE 8-SECOND INTERVALS PRECEDING, DURING, AND FOLLOWING THE VISUAL (CONDITIONED) STIMULUS

The composite means represent 175 measurements at each of the five intervals.

Subjects	1	2	3	4	5
I	76.2	75.9	72.2	78.8	65.9
II	88.5	75.6	71.2	74.0	85.7
III	73.5	47.9	48.2	56.0	74.9
IV	40.4	31.4	29.8	33.1	37.2
V	53.8	51.8	56.0	60.5	62.2
VI	75.6	63.9	60.3	71.4	73.8
VII	39.8	24.2	22.3	31.8	45.3
VIII	59.1	51.2	54.8	54.7	56.3
IX	118.9	80.6	88.7	105.7	95.3
X	61.8	59.4	53.0	50.4	53.2
XI	37.1	24.8	27.2	22.1	26.2
XII	49.0	33.7	28.3	49.7	58.7
XIII	65.0	51.3	59.7	72.8	58.2
XIV	81.4	84.3	81.4	92.1	73.4
XV	74.2	73.7	72.0	75.7	79.7
XVI	36.1	30.1	29.1	29.3	33.5
XVII	33.0	27.3	26.1	28.3	40.0
XVIII	55.3	44.5	44.8	46.3	43.5
XIX	61.3	55.7	56.2	45.0	51.6
XX	57.0	50.5	43.2	49.3	62.9
Total	1237.0	1037.8	1024.5	1127.0	1177.5
Mean	61.85	51.89	51.22	56.35	58.88
$P.E._M$	2.996	2.91	3.063	3.406	2.72
Diff.	9.96	.67	5.13	2.53	
$P.E._{Diff.}$	1.38	.63	1.11	1.48	
$\frac{Diff.}{P.E._{Diff.}}$	7.2	1.1	4.6	1.7	

Upton's animals showed 'a peculiar smoothing out of the breathing curve' when a tone was presented, and a 'true' conditioned response (excessive excursion of marker) occurred after the 500th trial.

Except for the fact that a visual conditioned stimulus was used instead of an auditory one, the present study of delayed conditioned responses in human subjects is comparable in many respects to the above animal studies. Occasional wide excursions of the recording stylus, similar to those reported by Upton, appeared at the end of the 16th second of delay, but these were the exception rather than the rule and may have been artifacts. However, the observations of

Lashley and Watson on conditioned respiratory changes (**25**), and the work of Scott (**21**), together with the extensive investigation of these changes by Garvey (**5**), all indicate that the isolated action of the conditioned stimulus frequently causes an increase in the magnitude of the reaction after conditioning has taken place. These studies utilized extremely short intervals between the conditioned and original

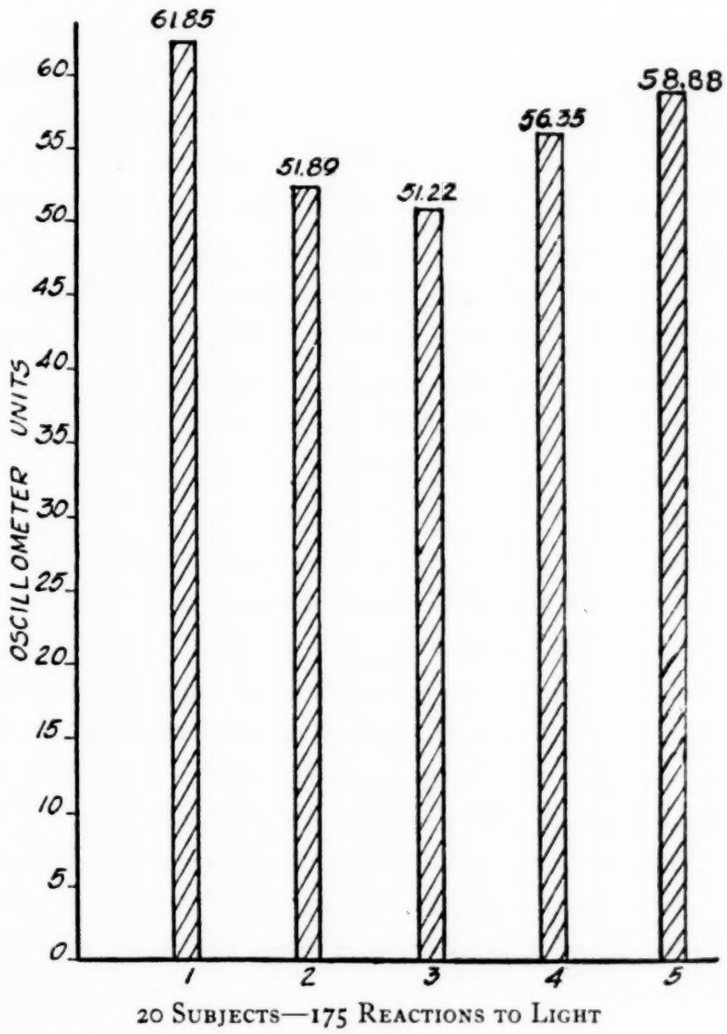


FIG. 5. Showing effect of the conditioned stimulus upon respiration during the interval of delay.

1. Volume of respiration during 8 seconds preceding onset of light.
2. Volume of respiration during first 8 seconds of stimulation by light.
3. Volume of respiration during second 8 seconds of stimulation by light.
4. Volume of respiration during 8 seconds following point at which reenforcement occurred during training. (The light was present during the first 5 seconds of this period.)
5. Volume of respiration during 8-second period between 3d and 11th second after removal of light stimulus.

stimuli. It is quite possible, therefore, that in the present investigation, and in the animal studies cited, the decrement during delay and the irregularity of the changes in amplitude at the end of the 16-second interval resulted from the spread of the 'inhibition of delay' which has been postulated by Pavlov (**18**). The verification of this hypothesis awaits the performance of certain critical experiments.

Smoothing of the breathing curve during the interval of delay occurred with 15 of the 20 subjects (see Table 4), though not in the marked degree represented in Fig. 4. This figure is a portion of the record of Subject VI, and the decrease in amplitude in this case is considerably greater than the average for the group as a whole. The decrement in amplitude of breathing, 'flutter effect,' to the light stimulus was manifest during the first two or three delayed presentations after the primary series of ten simultaneous light-shock stimulations. The phenomenon was less pronounced in the later stages of training, but reappeared during the experimental extinction series.

Summary

1. Anticipatory and inhibitory characteristics of delayed conditioned responses (galvanic skin response and respiration) were studied in 20 subjects in the main investigation. A supplementary study employing 9 of these subjects and a spontaneous recovery test of 5 subjects were made also.

2. A faint light of 21 seconds duration served as the conditioned stimulus. The original stimulus was a faradic current delivered to the index finger of the right hand for 1.2 seconds. The electro-tactual stimulus occurred at the end of the 16th second of continuous stimulation by the light, the conditioned stimulus continuing for 3.8 seconds after the termination of the original stimulus.

3. The latency of the anticipatory GSR to the conditioned stimulus (light) progressively increased from a mean of 5 seconds during the first four delayed light-shock presentations to a mean of 10 seconds at the end of the training period.

4. A rest period of 24 hours caused the anticipatory reaction to move forward again to its original position. A disin-

hibitory stimulus (loud buzzer) caused an immediate decrease in latency of the anticipatory reaction comparable to that produced by 24 hours rest.

5. In the test series a fairly marked decrease in volume of respiration was evidenced during the first 16 seconds of each presentation of the conditioned stimulus.

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THE NATURE AND MODIFIABILITY OF THE AUTOMATICALLY ASSOCIATED MOVEMENTS

An Experimental Study

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The coördination of muscular activity is present in all movement. Proper coördination is generally made possible by the harmonious interplay of agonist and antagonist muscle groups which operate as synergic units under the control of the central nervous system. A single synergic unit usually occurs in the individual only as a component of a more widespread movement-combination. This is due to the fact that these components are associated in a particular manner, and the apparent automaticity of their association is their most distinctive feature.

Movement-combinations of the nature to be described have been named differently by as many observers as have undertaken to observe them. Thus we find such terms as 'primitive automatisms,' 'higher coördinations,' 'associated movements,' 'position alterations,' 'reaction reflexes,' 'reflex synergias,' 'associated reaction movements,' and so on. Such terminological difficulties indicate that definite information concerning the exact nature of these reactions is lacking. At any rate, there are available movement-combinations which are quite accessible for study. An example of such automatically associated movements, a more detailed index of which will be given later, may be observed in the movement of the arms and legs in walking. The synchronism of the arm and leg movements indicates that the arms are apparently under control of the legs. One is reminded here of the absence of this synchronism in the Parkinsonian syndrome.

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The writer is indebted to Professor Raymond Dodge for his frequent advice and invaluable criticism during the course of this investigation, to Professor Roswell P. Angier and the Department of Psychology for rooms and encouragement, and for funds to build the apparatus.

The present investigation concerns itself with a preliminary experimental exploration of some psychophysiological aspects of one such movement-combination. By the study of this pattern-reaction when apparently normal, at least in the sense that the subject suffers from no neurological disease, it may be possible to discover the factors at work in the 'normal' operation of these movements. Some indication of causes of their changed status when they are pathologically disturbed may also be made. The investigation of such motor activity, therefore, becomes of interest from the standpoint of clinical as well as of pure science.

Existing Data

Some idea of the types of automatically associated movements which have been studied clinically in the past may be gained from a consideration of the following list.[2]

I. Head, face, and neck.

1. Shut eyes, with or without resistance; eyeballs roll up.
2. Turn eyes to side; head turns also.
3. Open mouth, against resistance; head extends.
4. Turn eyes up; forehead wrinkles, head extends.
5. In supine position, flex head on chest; recti abdominis contract.
6. Flex head against resistance; platysmas, omohyoids, hyoid depressors contract.
7. With head in one extreme lateral position (say, right) rotate it slowly to left; left posterior rotators contract first, and right sternomastoid only after head is well past the mid-line. And vice versa.

II. Shoulder, arm, hand, and fingers.

1. Abduct extended arm at shoulder; opposite erector spinæ contracts.
2. Abduct extended arm from horizontal position; homolateral rectus abdominis and erector spinæ contract (only if against resistance).
3. In erect position, advance extended arm to horizontal level in front—both erectores spinæ contract; rotate it horizontally backwards—homolateral erector spinæ at once relaxes; bring it forward again on horizontal level—the same erector spinæ contracts again; depress extended arm once more to side—homolateral erector spinæ once more relaxes.
4. With arm flexed at elbow and forearm pronated, supinate (biceps does this); triceps contracts to prevent further flexion at elbow.
5. Flex fingers in grasping; extensors of wrist contract. Increase grasping movements; triceps contracts.
6. Open closed hand; extensors of wrist relax; flexors of wrist contract.

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[2] From Wilson, S. A. K., *Modern Problems in Neurology*, 1929, Wood. Pp. 167, 168.

7. Extend flexed wrist with fingers closed—extensors carpi radialis and ulnaris contract; without stopping wrist extension, open fingers—the wrist extensors at once relax, while the extensors of the fingers continue the upward movement.
8. Press thumb firmly against forefinger; flexor carpi ulnaris contracts.
9. Abduct little finger; extensor ossis metacarpi pollicis contracts.
10. Extend thumb; extensor and flexor carpi ulnaris contract.
11. Abduct forefinger; thumb nearly always flexes or abducts and, if so, extensors of thumb contract.

III. Trunk and legs.

1. Supine position; lift one extended leg (*i.e.*, flex at hip); contralateral hamstrings (internal or external group, or both) contract.
2. Supine position; lift head and shoulders up; recti abdominis contract, then both recti femoris.
3. Erect position; abduct one extended leg at hip; opposite tensor fasciæ femoris contracts.
4. Flex spine—*i.e.*, bend forward (not against resistance); both erectors spinæ contract.
5. Bend backwards—*i.e.*, extend spine; recti abdominis contract. Combining (4) and (5), recti and erectores alternately contract and relax.
6. Incline spine to right or left; opposite erector spinæ contracts.

It will be noted that each of the movements enumerated are initiated voluntarily. Of this number two general types, (*a*) *movements of sequence*, and (*b*) *movements of simultaneous coöperation*, are distinguishable.

a. Movements of sequence: If, for example, one examines the movement described in I, 7; II, 7; III, 2; or III, 5 one may observe that movements are begun by one muscle or muscular group and continued by another. Beevor[3] has indicated that the order of action is apparently so fixed that if the failure of one component occurs no substitute is found. He states, "It rather reminds one of some highly organized establishments where, if one of the servants is incapacitated, it is no one's place to do the work, which is consequently left undone."

b. Movements of coöperation: Such movements may be seen in II, 5 and II, 6. In these cases the component movements are apparently simultaneous. Wilson has studied this particular movement in a normal individual with a tambour-kymograph technique. He has concluded from his study of various of these movement-combinations that in Parkinson-

[3] Beevor, C. E., Muscular movements and their representation in the central nervous system, cit. by Wilson, *l. c.*

ians "these movements are executed normally . . . that is to say, the movements follow normal physiological lines and are neither lost nor perverted."

Despite the distinction between movements of sequence and movements of coöperation it seems that with both these general types *optimal posture* is attained. For example, such movements as extension of the wrist with flexion of the fingers makes it possible for the hand to be in optimal grasp posture. Similarly, the swinging of the arms in walking achieves optimal walking posture and balance. Though normal, such an activity is not invariable since one can walk with his hands clasped behind his back or with his arms held stiffly in front or in some other 'artificial' manner. Similarly, the arms can be made to swing exaggeratedly to facilitate progress as is seen in runners. These illustrations are presented as a warning concerning the constancy of an 'associated movement' and its pure 'automaticity.'

The concept of posture in relation to the automatically associated movements has heretofore been only lightly touched upon by most writers. It would lead us too far afield to discuss posture intensively here, but some mention of this significant work must be made. The tonic neck reflexes, the tonic labyrinthine reflexes, the righting reflexes, and so on, become grist to the mill of study of the automatically associated movements when one examines these reactions. For example, De Kleijn has shown that when the head is rotated around the long axis of the body, the limbs toward which the jaw is facing acquire an increased extensor tonus with an accompanying relaxation of tonus in the other limbs. The neck righting reflexes are of particular interest to us in our present investigation. It might be mentioned that since posture involves a change in tonus, if, indeed, it is not true that tonus *is* posture, the theoretical implications of our study of the automatically associated movements become still more complex.

Restatement of the Problem of This Report

The foregoing discussion indicates that few investigators have studied the automatically associated movements from

the standpoint of their normal physiology in the intact individual. Wilson's tambour-kymographic technique is open to many technical objections such as variations in rubber tension, tube length, friction of the pointers on the smoked drum, and elasticity of the air. Under such conditions, indeed, the exact nature of the movements might well be masked. Furthermore, no study has attempted an evaluation of these movements from the standpoint of the variations which changes of experimental conditions might produce. Evidence of the influence of factors such as repetition, general and selective fatigue, and so on, is certainly lacking.

In the present investigation one automatically associated movement is studied by methods of photographic registration. Such a method involves the technical advantages of rigid levers and light reflecting devices which avoid the inertia and momentum of magnifying levers and all delay from any cause such as friction. The particular movement-combination studied was the action of the abdominal musculature which followed the raising of the head and shoulders and was followed by action of the thigh musculature (*cf.* p. 3, III, 2).

Apparatus

Inasmuch as the particular combination of movements studied in this investigation necessitated the registration of motions and muscular contractions from rather widely separated parts of the body, the present apparatus was constructed to make possible the simultaneous recording of all movements by means of optical levers displacing a recording beam of light. Although it is true that the particular components observed do not include all the units which enter into this particular movement combination, it was assumed that those which were studied might be taken as representative of the entire pattern.

The factors studied were (1) gross movement of the head recorded from the forehead, (2) movement of the head as indicated by chin movement, (3) shoulder movement, (4) activity of the right rectus abdominis as recorded by its thickening, (5) activity of the right rectus femoris as recorded by its thickening.

1. *Movement of the Forehead*

Since the components of the reaction pattern are best elicited when the forehead is raised actively against resistance, a mechanism was constructed which made it possible for the forehead to move through any distance against resistance. A block was arranged so that when placed upon the subject's forehead it could be raised or lowered in accordance with the head movement against stiff wire springs, the tension of which was adjustable. In this manner the amount of resistance could be varied experimentally. In the experiments to be described the spring tension was 15 lbs. A record

of the displacement of the forehead was procured by a system of levers attached to an optical system (*cf.* below).

2. *Movement of the Chin*

Displacement of the head becomes first noticeable as chin-movement under the conditions imposed by this apparatus. Registration of this movement was made possible by a lever weighted just sufficiently to rest without overthrow upon the chin. This lever operated on an axis and was connected by a pulley to its optical lever.

3. *Movement of the Shoulder*

A shoulder-strap served to connect the body with levers which were connected with an optical lever. The shoulder-strap was fitted very closely so that the slightest displacement of the shoulder was effective in displacing the recording beam of light.

4. *Activity of the Rectus Abdominis*

This component was recorded by muscle thickening. A weighted lever was placed upon the right rectus abdominis muscle one inch above and to the right of the umbilicus and was connected by a pulley to an optical lever.

5. *Activity of the Rectus Femoris*

This component was recorded in the same manner as (4) except that the weighted lever was placed upon the right rectus femoris muscle seven inches below the middle of Poupart's ligament.

It must be noted again that the record of the rectus abdominis, and the rectus femoris do not record activity of these muscles alone. Displacements of the levers at these respective positions are probably due to activity of entire muscle groups in these regions. For example, it is probably true that displacements of the lever placed on the thigh are due to activity not only of the quadriceps but also of the hamstring groups, and that displacements of the beam of light are no less due to activity of the quadriceps than of the hamstrings.

The optical levers which may be considered the heart of the recording technique were the same for each of the components studied.[4] Each recording unit consisted of a spindle which ran freely on cone bearings. This spindle had upon it a circular groove which served as a pulley to be connected with the levers upon the body. Each spindle had upon it three small concave mirrors of 9 inch focus fastened by small pieces of wax. In each instrument the three mirrors were arranged one above the other, and were adjusted in such a manner that the light beams which they reflected were 3.5 inches apart at one meter (the distance to the camera). As one beam completely traversed the width of the photographic paper (3.5 inches) another beam would fall upon the slit. The purpose of this arrangement was to make it possible to record gross movements, magnified by the lever and pulley arrangements, and by the one meter distance from the mirrors to the camera, upon the photographic paper. Each mirror reflected its beam horizontally into the camera from separate slit-lamp sources vertically above it. Each transmitted beam was a reflection of the filament of a 75 watt clear Mazda bulb.

The camera employed was the usual Yale laboratory type holding a roll of sensitized paper which could be passed before the slit upon which the light beams from the optical levers fell. The paper was moved across the slit by the friction between two

[4] The optical lever here described owes its construction to the ingenuity of Professor Dodge.

rollers, one of which, driven by a spring phonograph motor, rotated the other. The speed of the paper could be regulated by altering the pulley system and the speed of the motor. Within the slit was placed a silk grid whose threads were placed 2 mms apart. At each 10 mm mark a thicker thread was interposed. This grid facilitated the quantitative readings of the displacements of the beams.

The time line was made by a small Stoelting electro-magnetic marker in a circuit with a Newhall timer.[5] The entire apparatus was installed in a photographic dark room, and was firmly fixed on heavy tables in order to minimize adventitious vibrations.

Experiments and Results

Each of the experiments to be described and discussed below will be presented in four divisions: (1) experimental conditions, (2) results, (3) discussion of the data, (4) summary.

Experiment 1

Nature and Variability of the Movements

(1) *Experimental conditions.*

The subject lay supine upon the table, the head resting upon a thin felt pad. The arms were adducted and the palms held close to the sides; the legs were adducted so that the feet touched each other on their medial aspects and were tied together about the metatarsals. The subject was instructed as follows: "The head is to be lifted up as far as it can go after which you are to raise your shoulders; when this position has been sustained for 4 metronome clicks (2 seconds), you are to allow your head and shoulders to drop back to the table. At the given signal (1 second before the onset of the trial) you are to hold your breath, and to sustain it until the trial is over. You are to do this ten times." Trials were spaced at 5 second intervals.

(2) *Results.*

Since it was observed that movement upward and downward of the chin always precedes activity of the other components, the delay of reaction of the other components is taken from the moment of movement of the chin.

Table 1 presents the average delay for 10 trials of each component of the reaction-pattern with reference to the chin movement.

[5] The writer is indebted to Dr. Sidney M. Newhall for the use of this instrument.

TABLE 1

DELAY OF MOVEMENT (IN SEC.) OF THE PATTERN COMPONENTS (CHIN TAKEN AS ZERO)

Movement Upward			
Head	Shoulder	Abdomen	Thigh
·73	·45	·36	·58
Movement Downward			
·67	·43	·42	·61

(3) *Discussion of the Data.*

From the records and the data presented above, the following points have been noted:

(*a*) The activity of each component occurs in a definite order of sequence; rarely does any movement begin simultaneously with any other. This generalization applies to both movement upward and downward.

(*b*) Movement of the forehead, both upward and downward, is apparently always last. This does not mean that the head muscles have not been in activity before the apparent onset of movement (as is evidenced by chin movement), but rather is to be interpreted as the period during which muscular strain is being built up or released in the head-moving muscles to balance the resistance upon the forehead. We shall return to this point in a moment.

(*c*) The order of sequence of the movement components is not absolutely fixed. Although this may be due to technical difficulties in reading the records, it cannot be said that set sequence always occurs. These data would tend to refute Beevor's statement (p. 3) in which the components were said to be 'so fixed physiologically that never are they lost or perverted.' The significance of this contradictory evidence is that single records of a similar automatically associated movement studied in individuals suffering from neurological disease which would modify these movements must be interpreted cautiously. Furthermore, individual differences

are probably much greater than the variations within the same individual over a period of some 50 seconds as here described.

(*d*) The general pattern of sequence, however, which may be considered as typical under this set of experimental conditions is as follows: when an attempt is made to lift up the head there ensues activity of the abdominal muscles which in turn is followed by activity of the thigh muscles.

(*e*) Another set of automatically associated movements may be described from the movement-downward combination. This combination is almost the reverse of the pattern indicated by Wilson as III, 2. It may be stated in this manner: if, with the subject in a supine position with the head and shoulders lifted slightly off the table, the head and shoulders are dropped back, the abdominal muscles relax followed by relaxation of the thigh muscles. This downward movement occurs more quickly, in general, than the upward movement.

(*f*) The chin-head relationship requires more analysis. There is no doubt that when the chin moved, the head moved with it, for the jaw was kept tightly closed. The forehead movement occurred afterward, as shown by the records, and has been attributed to the upbuilding and release of strain in the head musculature. Another possibility which must be considered is that the head can move most readily when it is in an optimal posture. This posture, which is some spatial position between maximal flexion, maximal extension and optimal point of rotation, is determined probably by the amount of load upon it. There is at hand some graphic evidence that at the very onset of chin movement upward there is a slight retraction (extension) of the forehead before it moves upward (flexion); also, when the chin was moved downward for a certain distance the forehead, before being lowered, moves just a little further upward (flexion) than the position in which it had been sustained. The occurrence of this phenomenon is variable and its significance is not clear. This circumstance is, however, of psychological interest since the implication is that a given member of the body will be placed in the optimal position which the circumstances allow, a

'physiological set,' as it were, and comparable perhaps to 'mental set.'

(4) *Summary.*

The description by Wilson of the sequence of components in automatically associated movements in which the contraction of the abdominal and thigh muscles follows attempt to lift the head and shoulders from the supine position is confirmed. Evidence is at hand, however, which indicates the existence of variations in the order of sequence in the same individual at different times. A tentative hypothesis of physiological set in head posture on the basis of our records is presented. A new movement-combination which may properly be considered an automatically associated movement is described.

Experiment 2

The Effects of Repetition and Fatigue

(1) *Experimental Conditions.*

(*A*) Subject in posture described in Experiment 1. Instructions: "You are to lift and drop your head and shoulders as quickly as you can, until you are told to stop."

(*B*) Conditions similar except for Instructions which were: "You are to lift and drop your head and shoulders but you are to keep time to the metronome until you are told to stop." The metronome beat occurred every 2 seconds.

(*C*) Conditions similar except for Instructions which were: "You are to lift your shoulders but you are to drop them only when you can no longer keep them lifted, until you are told to stop."

Instructions to stop were not given in any of the above experiments, the respective experiments being allowed to continue until the subject was unable to continue. Each of the experiments were conducted at different experimental sessions.

(2) *Results.*

(1) The number of movements performed before the onset of complete exhaustion under each of the above conditions is presented in Table 2.

TABLE 2

NUMBER OF MOVEMENTS MADE UNDER EACH CONDITION

A	*B*	*C*
31	48	5

(2) Relative time-intervals of each component were determined in units of 0.01 sec. These data (Table 3) are calculated in the same manner as in Experiment 1, viz: delay periods of reaction with onset of chin-movement as the point of reference.

TABLE 3

DELAYS (IN SEC.) OF MOVEMENT OF EACH COMPONENT UNDER DIFFERENT FATIGUE CONDITIONS (CF. *A*, *B*, AND *C* ABOVE)

Movement Upward

Trial	*A*				*B*			
	Forehead	Shoulder	Abdomen	Thigh	Forehead	Shoulder	Abdomen	Thigh
1–5...	.69	.41	.35	.62	.81	.37	.29	.51
15–20..	.30	.17	.14	.24	.67	.30	.21	.30
25–30..	.42	.21	.74	.16	.38	.21	.19	.27
40–45..					.95	.78	*	.31

Movement Downward

1–5...	.51	.28	.37	.46	.65	.38	.29	.42
15–20..	.37	.21	.07	.20	.41	.26	.21	.35
25–30..	.12	.09	.12	.18	.09	.10	.17	.25
40–45..					.09	.12	*	.29

C

Trial	Duration †	*Movement Upward*				*Movement Downward*			
		Forehead	Shoul.	Abd.	Thigh	Forehead	Shoul.	Abd.	Thigh
1.....	8.32	.82	.53	.41	.58	.75	.47	.35	.75
2.....	8.75	.65	.49	.43	.55	.41	.48	.42	.41
3.....	4.51	.34	.31	.26	.24	.43	.24	.31	.43
4.....	3.09	.32	.27	.19	.39	.13	.15	.33	.13
5.....	1.20	1.23	‡	‡	.21	.15	‡	‡	.13
							.00	.00	

* Recording lever had fallen off body between Trials 30 and 40.

† Duration is defined as that time interval (in sec.) between the moments of completion of upward movement of the head and the beginning of its downward movement.

‡ The record showed no movement.

(3) *Discussion of the Data.*

From these data the following points may be noted:

(*a*) The relative sequence of movement components in *A*, *B*, and *C* is similar to that described in Experiment 1.

(*b*) The average delays of Trials 1–5 are closely similar in both *A* and *B*.

(*c*) In Trials 15–20, the average delays of both *A* and *B* are shorter than in Trials 1–5, the relative decrease in *A* being greater than that in *B*.

(*d*) In Trials 25–30, the average delays of *B* become shortened to the place where they are closely similar to those of *A* in Trials 15–20.

(*e*) In Trials 25–30 for *A*, and in Trials 40–45 for *B* there may be observed that the average delays do not follow in the order of progressive diminution which characterizes the previous trials, but rather seem entirely bizarre.

From the above considerations the following generalizations may be made:

(1) As the particular movement combination is produced successively, the components of the combination tend to occur more quickly and with an apparently definite approach toward simultaneity.

(2) This phenomenon occurs more quickly the more rapid the succession of consecutive pattern-reactions.

(3) Fatigue and exhaustion of the forehead component occurs more quickly the more rapid the succession of reactions.

(4) These generalizations apply to the activity of the downward movement as well as to the upward movement.

(5) There is a point in the course of the fatigue of the initiator (head) of the movement-combination after which the time relations of the components are greatly disturbed. Exhaustion apparently sets in when this stage has been reached.

(*f*) In *C*, it may be seen that the ability to sustain upward movements decreases progressively in successive trials.

(*g*) In *C* also may be noted that the relative delays become generally progressively shorter from Trial 1 to Trial 5 for each component of both upward and downward movement. Here also the approach to simultaneity is indicated.

(*h*) In the later trials the sequence of reaction of the different components becomes more variable, apparent exhaustion ensuing after 5 trials only.

From these data (Statements *f–h*) the following generalization may be made: maintenance or fixation of the automatically associated movement at any attempted maximum is very fatiguing even after a very few trials. The tendency toward *more unified mass action*, *i.e.*, the approach to simultaneity of the different components, is again visible for both upward and downward movements. Here again, extreme fatigue tends to disturb profoundly the time relations of action of the different components.

(4) *Summary.*

Evidence is presented that under three conditions which induce repetition and fatigue (movement as rapid as possible; movement set to a fixed rhythm; and movement maintained at maximal posture as long as possible) there is a pronounced tendency toward modification of the pattern of the automatically associated movements. This modification includes (*a*) rapid *telescoping* of the reaction times of each component so that a tendency to simultaneity, or *unified mass action* is produced, (*b*) subsequent fatigue of the initiator of the reaction-pattern, which ultimately produces disturbance of the relative sequence and regularity of the other components, which though themselves not fatigued,[6] become dissociated from their fellows with respect to time.

Experiment 3

The Effects of Sustained Position

The experiments described above have been concerned mainly with the relationship of the time intervals of the components of the movement-combination, and the factors which modify these time intervals. The present experiment is concerned with a consideration of the relative amplitudes of

[6] Available records indicate that the decreasing amplitude of response characteristic of fatigue of the forehead movement is apparently unrelated to changes in amplitude of movement of the other components of the movement-combination. (*cf.* Experiment 4.)

response of the several components and the factors which modify this aspect of their activity.

The values presented below do not represent amplitude records of actual response. Since the excursion of the forehead, chin, and shoulder movements are relatively so much greater than the excursion of the movement produced by abdominal and thigh muscular activity, several features of the apparatus were designed to make all movements technically recordable. Recorded amplitudes of forehead, chin, and shoulder displacements are proportional miniatures of actual movement; recorded amplitudes of abdominal and thigh muscular activity are proportionately magnified. Our records, therefore, do not display absolute differences in amplitude of response of the different components because of the different mechanical limitations placed upon each one. This factor, however, in no way minimizes the significance of relative differences in amplitude in the same component which may occur under various experimental conditions.

(1) *Experimental Conditions.*

Same as in Experiment 2*C*.

Readings of the amplitude displacement were made directly from the photographic record. Records were read to the nearest 0.1 mm with the assistance of a lens.

(2) *Results.*

Table 4 presents the amplitude of each component of the movement-combination in the 5 consecutive trials of the experiment.

TABLE 4

AMPLITUDE OF MOVEMENT OF EACH COMPONENT (IN MM) IN 5 CONSECUTIVE TRIALS

Trial	Duration (sec.) *	Chin	Head	Shoulder	Abdomen	Thigh
1.....	8.32	73.4	52.0	42.3	10.8	8.2
2.....	8.75	65.3	47.8	36.2	12.1	9.1
3.....	4.51	57.7	32.0	41.7	9.2	9.1
4.....	3.09	58.2	36.6	22.5	10.6	7.5
5.....	1.20	10.1	4.6	12.8	16.4	15.3

* See second footnote † of Table 3, *C*.

(3) *Discussion of the Data.*

From these data the following features of significance seem to be indicated:

(*a*) The duration of the maintained position diminishes, so that by the last trial (followed by complete inability to move the head), it is extremely short. This confirms statements as to the fatigue-value of maintained posture during which no apparent work is being performed.

(*b*) The head (including the chin) and shoulders undergo progressively smaller amplitudes of movement characteristic of oncoming fatigue. It is interesting to note that the curve of progression is not a smooth one and that 'collapse' occurs with rather dramatic suddenness at Trial 5. This sort of phenomenon has often been advanced in support of the theory of 'psychological' fatigue as against 'physiological' fatigue. Whether or not this 'collapse phenomenon' has been observed previously in work experiments involving fixation-activity of a nature similar to the condition in our experiment is not known to the writer. In any case, the presence of suppositious psychological influences in our movement-combination is demonstrated.

(*c*) The abdominal and thigh musculature show no diminution of excursion which one might expect with the onset of fatigue. It is almost a commonplace that fatigue of one part of the body increases the fatiguability of other parts due to the circulation of fatigue products from the exercised region. However this may be, our data demonstrate no concomitant fatigue of the abdominal and thigh components. This may be due to difference in load upon the various components.

There is an additional observation here which cannot be easily explained: in Trial 5 the abdominal and thigh components are much greater than they have been in previous trials. The explanation of this may be that with the exhaustion of the initiator of the movement-combination, those components which under 'normal' conditions react with a certain intensity may take up the task of accomplishing adequate posture and so compensate for deficiencies of the other components.

(4) *Summary.*

Data which demonstrate the relationship of amplitude of movement of the various components to each other under conditions of fatigue due to fixation of position, are presented. Fatigue of a given component seems to bear no special relationship to fatigue of any other. Those components which act under less load react more intensely when the more greatly loaded components approach exhaustion.

Experiment 4

The Effects of Selective Exercise

As a rather obvious corollary of Experiment 3, the question of the effect of fatigue of the abdominal and thigh musculature upon the entire movement-combination arises. The present experiment is an inquiry into such a possible relationship.

(1) *Experimental Conditions.*

(*A*) Same as Experiment 1. Five movement-combinations at 5 second intervals and sustained for 2 seconds were elicited. After a 15 second rest the subject was requested to voluntarily contract and relax the quadriceps musculature every 2 seconds to the beat of a metronome. This was done 50 times, following which, for 5 trials, at 5 second intervals, the entire movement-combination was brought into play by voluntary lifting of the head and shoulders, the upright position being sustained for 2 seconds.

(*B*) Same as Experiment 1. Five movement-combinations at 5 second intervals and sustained for 2 seconds were elicited. After a 15 second rest the subject was requested to voluntarily contract and relax the musculature of the anterior abdominal wall [7] every 2 seconds to the beat of a metronome. This was done 20 times following which, for 5 trials, at 5 second intervals, the entire movement-combination was brought into play by voluntary lifting of the head and shoulders, the upright position being sustained for 2 seconds.

Experiments (*A*) and (*B*) were performed at different experimental sessions.

[7] Exactly how this was done is difficult to describe. A little practice is necessary for the novice; the movement resembles rapid voluntary abdominal respiration with considerable straining.

(2) *Results.*

Since the conditions are so similar the results of *A* and *B* (Tables 5–10) will be considered together.

(1) For both the thigh and abdominal musculature the amplitude of movement decreased very little, if at all, from the beginning to the end (Tables 5 and 6). From this standpoint the fatiguability of such voluntary movements is therefore, small.

TABLE 5

AMPLITUDE OF MOVEMENT (IN MM) OF PATTERN COMPONENTS DURING EXERCISE OF QUADRICEPS MUSCULATURE

Trials	Chin	Forehead	Shoulder	Abdomen	Thigh §
1–5.....	—	—	3.3†	7.6‡	9.3
6–10.....	—	—	4.1*	—	10.2
11–15.....	—	—	—	1.5†	8.6
16–20.....	—	—	—	7.9*	7.5
21–25.....	—	—	—	—	11.4
26–30.....	—	—	—	—	9.3
31–35.....	—	—	—	8.1*	6.5
36–40.....	—	—	2.1*	4.1*	10.9
41–45.....	—	—	—	—	8.6
46–50.....	—	—	—	—	9.7

* 1 case.
† 2 cases.
‡ 3 cases.
§ 5 cases.

TABLE 6

AMPLITUDE OF MOVEMENT (IN MM) OF PATTERN COMPONENTS DURING EXERCISE OF ANTERIOR ABDOMINAL WALL

Trials	Chin	Forehead	Shoulder	N*	Abdomen	N*	Thigh	N*
1–5.....	—	—	6.2	2	12.5	4	4.3	1
6–10.....	—	—	—	0	13.6	5	—	0
11–15.....	—	—	1.6	1	15.1	5	—	0
16–20.....	—	—	—	0	11.2	5	—	0

* Number of cases.

(2) Toward the completion of these voluntary movements, however, the pattern of contraction-fixation-relaxation of the abdominal and thigh activity became very much varied in that the relationship between these three aspects of muscular activity became quite chaotic (Table 5). Here again one was reminded of the changes in time-relations between components rather than in amplitude of movement in fatigue of the automatically associated movements in previous experiments.

(3) It was observed from the records that for both the abdominal and thigh musculature, there occurred a progressive building-up of the level to which the musculature returned (as relaxation) after contraction. This is interpreted as a progressive increase of tonus during muscular activity, and

TABLE 7

AMPLITUDE OF MOVEMENT (IN MM) BEFORE AND AFTER EXERCISE OF THE QUADRICEPS MUSCULATURE

Trial	Chin		Forehead		Shoulder		Abdomen		Thigh	
Relation to Exercise *	1	2	1	2	1	2	1	2	1	2
1.....	89.1	92.6	65.2	63.2	46.5	61.2	14.7	22.6	6.5	15.2
2.....	72.6	84.7	58.1	72.1	39.5	52.3	9.3	14.3	14.3	15.5
3.....	83.7	89.6	72.3	65.3	51.7	51.7	13.8	15.0	10.9	12.1
4.....	79.9	79.5	62.1	81.7	58.7	71.3	16.3	19.6	8.7	8.6
5.....	88.7	76.5	89.6	71.0	46.2	57.2	11.1	17.7	9.4	10.9
Average...	82.8	84.6	69.4	70.6	48.5	58.7	13.0	17.6	10.0	12.5

* Columns 1 and 2 refer to the pre-exercise and post-exercise conditions respectively.

TABLE 8

AMPLITUDE OF MOVEMENT (IN MM) BEFORE AND AFTER EXERCISE OF THE ANTERIOR ABDOMINAL WALL

Trial	Chin		Forehead		Shoulder		Abdomen		Thigh	
Relation to Exercise *	1	2	1	2	1	2	1	2	1	2
1.....	85.2	86.1	72.1	69.2	51.7	63.2	12.1	17.5	7.5	8.3
2.....	86.5	81.2	82.7	82.8	62.3	65.6	10.9	10.6	14.9	15.1
3.....	75.4	91.3	68.1	62.3	41.6	42.1	15.6	21.3	10.7	11.9
4.....	73.4	69.7	56.3	79.6	51.9	69.3	19.1	19.7	15.1	13.8
5.....	91.7	82.6	75.5	59.4	47.9	58.6	9.9	14.4	8.9	10.3
Average...	82.4	82.2	70.9	70.7	51.1	59.8	13.3	16.7	11.4	11.9

* Columns 1 and 2 refer to the pre-exercise and post-exercise conditions respectively.

has been demonstrated by Dodge.[8] It may be the condition of 'plastic tone' to which physiologists often refer.

(4) Activity in the components other than the one being voluntarily exercised was either absent or minimal. Activity, more or less concomitant with voluntary activity of the

[8] Dodge, R., The laws of relative fatigue, *Psychol. Rev.* 1917, **24**, 89–113.

abdomen, was visible in exercise of the thigh (Table 5). With voluntary activity of the leg also very little movement of the other components was recorded (Table 6).

(5) When the drill for the abdomen and thigh was completed and the entire movement-combination elicited and compared with those preceding the drill, the following features of interest were noted:

(*a*) Amplitude of chin and forehead excursion was practically the same, on the average, in the 2 sets of 5 trials (Tables 7 and 8).

TABLE 9

DELAY OF MOVEMENT (IN SEC.) OF THE PATTERN COMPONENTS BEFORE AND AFTER EXERCISE OF THE QUADRICEPS MUSCULATURE

Before Exercise

Trials	Forehead		Shoulder		Abdomen		Thigh	
	U*	D†	U	D	U	D	U	D
1	.85	.73	.41	.37	.29	.34	.57	.55
2	.75	.81	.39	.42	.32	.37	.49	.51
3	.69	.68	.37	.47	.30	.28	.47	.49
4	.76	.79	.40	.37	.28	.29	.51	.46
5	.72	.77	.36	.29	.30	.35	.41	.49
Average	.754	.756	.386	.384	.298	.326	.490	.500

After Exercise

Trials	Forehead		Shoulder		Abdomen		Thigh	
	U	D	U	D	U	D	U	D
1	.76	.69	.43	.41	.34	.39	.61	.48
2	.85	.81	.52	.48	.48	.45	.52	.62
3	.86	.77	.38	.39	.37	.29	.47	.35
4	.75	.69	.45	.41	.24	.42	.32	.51
5	.69	.72	.50	.36	.21	.20	.54	.42
Average	.782	.736	.456	.410	.328	.350	.492	.498

* Movement upward.
† Movement downward.

(*b*) The amplitudes of movement of the other components, however, were much increased *after* the drill for *all* components (Tables 7 and 8).

(*c*) There was no reliable difference in the relative time-intervals between components of the combination before and after exercise (Tables 9 and 10).

From these data, it may be seen that, although voluntary exercise of minimally loaded musculature produces no observable differences in the time relations of the entire pattern of which it is a part, such exercise does affect the other components with respect to their intensity of reaction, in the direction of an increase of amplitude.[9]

TABLE 10

DELAY OF MOVEMENT (IN SEC.) OF THE PATTERN COMPONENTS BEFORE AND AFTER EXERCISE OF THE ANTERIOR ABDOMINAL WALL

Before Exercise

Trials	Forehead		Shoulder		Abdomen		Thigh	
	U*	D†	U	D	U	D	U	D
1	.79	.82	.40	.51	.30	.49	.49	.46
2	.82	.72	.39	.42	.36	.45	.45	.62
3	.77	.68	.42	.39	.33	.37	.51	.61
4	.85	.76	.51	.48	.29	.41	.44	.52
5	.79	.90	.38	.36	.34	.34	.56	.55
Average	.804	.776	.422	.432	.324	.412	.490	.552

After Exercise

Trials	Forehead		Shoulder		Abdomen		Thigh	
	U	D	U	D	U	D	U	D
1	.67	.70	.37	.51	.22	.47	.39	.64
2	.82	.75	.41	.47	.35	.39	.45	.51
3	.79	.82	.38	.42	.41	.41	.51	.52
4	.90	.69	.51	.39	.29	.37	.37	.36
5	.65	.74	.27	.37	.38	.28	.49	.43
Average	.766	.740	.388	.432	.330	.384	.442	.488

* Movement upward.

† Movement downward.

(3) *Discussion of the Data.*

The most salient feature of this experiment is the apparent carry-over of tonus from an exercised component of the reaction-pattern to the other components in the system. If the built-up tonus ('plastic tone') [10] increases the powers of con-

[9] The introspective report in this connection is of interest. It was stated that the performance of the entire movement-combination after exercise was a welcome relief from the tiresome monotony of the drill period.

[10] 'Plastic tone' and 'contractile tone' are illustrated as follows: "Consider the knee-jerk in a decerebrate animal. It can be shown graphically to consist of a single

tractility (increased 'contractile tone') [10] of the other components, one may postulate that if increased tonus of one component of an automatically associated movement occurs, there is a concomitant increased contractility ('tonicity'?) of the other components. This transfer effect may actually be more widespread so that perhaps many of the muscles of the body attain a heightened tonus; in any case, the condition does occur in the components of an automatically associated movement, and by its nature modifies these components.

(4) *Summary.*

Evidence which shows a positive relation between heightened tonus due to exercise of one component of an automatically associated movement and movement amplitude of the other components is presented. It was demonstrated that under such a condition of increased tone, there is a consequent increased amplitude of movement of all components including the exercised component. This was taken to mean that there is a transfer of tonus effect throughout the body which increases the general intensity of reaction of the pattern. Another factor which modifies the pattern-reaction is, therefore, described.

General Summary and Conclusions

Exploratory investigation of the nature of a so-called automatically associated movement has been reported in the preceding pages. Of particular interest has been the study of normal variability and the evaluation of other experimental factors. The term exploratory is used advisedly since of the multitudinous ramifications of the general problem, no one has been exploited. What some of these ramifications are, and the significance which they may have, is the subject of the present section. The experiments previously reported will serve as points of departure.

twitch followed by a continued contraction of the quadriceps muscle, which causes this muscle to assume a new and shorter length after the jerk. The twitch or jerk may be said to represent the 'contractile' factor and the continued contraction the 'plastic' element." From Brain, W. R. and Strauss, E. B., *Recent Advances in Neurology*, Blakiston, Philadelphia, 1930, 2d ed., p. 121.

"In the supine position, when the head and shoulders are lifted up, the recti abdominis contract, then the recti femoris" (Wilson).

This statement has been shown to be essentially correct by our records. This qualification must be made, however. Neither Wilson's statement nor our own records tell the whole story. For, *attempt* to lift the head, during which muscular strain is built up, is sufficient to initiate the sequence. Secondly, the contraction of the recti abdominis and of the recti femoris do not occur alone, but rather act as units of the musculature of the entire anterior abdominal wall, and of the entire quadriceps group respectively. Simple palpation of the muscles of these groups will prove this fact. Wilson's statement should, therefore, take account of these factors. But, even in this qualified form the statement is not yet completely accurate since (and this too can be confirmed by palpation) the anterior abdominal and femoral groups *contract together with their antagonists.* It is only in this way that the trunk and thigh are converted into respective rigid pillars which only as such can make movement of the entire segment possible. The term 'contraction' must, therefore, become 'co-contraction' and all the muscles in the particular limb segment be included in the statement of the movement. Conversely, there is a 'co-relaxation' of the muscles when the head and shoulders are returned to their former position. It would be irrelevant for us to elaborate here any further considerations concerning the agonist-antagonist relationship.[11] The important point for us is the fact that in the performance of this automatically associated movement the tonicity of the units of an entire segment probably varies concomitantly. As applied to our records, therefore, displacement of the thigh lever (say) is due as much to contraction and relaxation activity in the ham-strings as in the quadriceps; the automatically associated movement, therefore, involves much more complex units than is at first apparent.

The order of sequence of the components may be considered typical as described. A factor of variability exists,

[11] *Cf.* Dodge, R., and Bott, E. A., Antagonistic muscle action in voluntary flexion and extension, *Psychol. Rev.*, 1927, **34**, 241–272.

however, and must be considered when utilizing an apparently typical record for comparative purposes. That they 'do not become lost or perverted' as stated by Beevor, does not seem to be entirely the case, for although we have found no records in which any of the components were lost, variations of the nature of different order of sequence and different amplitudes of reaction were observed. Of these two types of variation the former was relatively infrequent; the latter, however, was often observed and has been studied.

Some of our records indicate the presence of another factor which may be of prime significance in the entire program of our investigation. It was observed that for the head there was a period preceding movement in which it adjusted itself to a new position. This posturing of the head has been taken to indicate a physiological set for most effective action. The position 'selected' by the head as optimal, varies very probably with the load upon it, the general bodily posture, the tonicity of the associated components, and other factors which our investigation of this phenomenon has not yet elicited.

The release from a tonically maintained posture produces an automatically associated movement in a sequence the same as that which produced it. If in an upright position, the head and shoulders are dropped back, relaxation of the associated components (abdomen, then thigh) occurs in a fairly definite pattern. Co-relaxation of components associated into a pattern therefore, may be considered to constitute a characteristic automatically associated movement as well as the co-contraction pattern. Here also variability exists with respect to both order of sequence and amplitude of movement. It seems to be true that return of a muscle to its *original* state after activity is impossible because of a residuum of tonicity which forbids relaxation to its original level.

The problem of the relationship between the automatically associated movements and bodily posture is presented here. Every movement in the body effects a new posture and automatically associated movements are no exception. Experi-

mental evidence has been presented which demonstrates that with repetition the components of the movement-combination tend to approach the state of more simultaneous activity. This telescoping of reaction times has been interpreted to indicate a mechanism on the part of the body whereby more unified or simultaneous coöperation may produce postural change more quickly and effectively. This would infer that movements of sequence may under certain conditions actually become movements of simultaneous coöperation and to try to differentiate types of automatically associated movements in this manner may be unnecessary. One may conjecture that the automatically associated movements in the body which occur in sequence, do so until the necessity for more effective action arises in which event the components tend to react simultaneously. Whether or not they actually are simultaneous from the standpoint of neural discharge cannot be said. Perhaps here the mechanism is one of simultaneous innervation of co-reactors of the nature of reciprocal innervation.

More evidence in support of these generalizations is presented in our fatigue experiments. When the head and shoulders approached exhaustion no similar effect could be noted in the other components and indeed when the former were at the point of exhaustion, an *increase* of intensity of reaction became visible in the latter. This may mean that the abdominal and thigh musculature strive to attain the posture which the whole movement-combination brings about by compensating for the failure of their fellow components.

Our problem, therefore, involves consideration of tonus as well as of posture and movement. Experimental evidence has been produced here which may throw some light upon the relationship between tonus and the automatically associated movements. Extended exercise of one component of the pattern alone produced in itself and in the other components an increased amplitude of reaction when the entire movement-combination was elicited. An increase in tonus in the exercised component was demonstrated as its exercise proceeded; why this increasing residuum of tonus should be carried to the

other components and increase their contractility, is problematical. These conditions produced no effect on the relative reaction times. The carry-over of plastic tonus to contractile tonus in this fashion is of great physiological interest and may indeed be of significance for the psychological aspects of the general problems of set, tension, strain, and movement.

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SIZE OF STIMULUS IN RELATION TO THE EYE'S SENSITIVITY TO LIGHT AND TO THE AMOUNT AND RATE OF DARK ADAPTATION

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Before the testing of the light sense can be safely and effectively given a practical application it must be subjected to a preliminary process of standardizing. Methods must be devised and adopted which eliminate or hold constant the influence of variable factors and instruments must be designed which make the use of these methods readily and conveniently possible. In a previous paper[1] two of the present writers have described an instrument the design of which was based on studies which we have made of the factors that influence the results obtained in testing the light sense.

Among the factors which influence the results of light-sense tests in a given eye the following may be noted: wave-length and composition of light, previous conditions of exposure of the eye and state of adaptation, size of stimulus, relation of size of the preëxposure field to size of stimulus, distance of test field, size of pupil, part of retina stimulated and degree of freedom of the cornea from obscuring films. For the factors which influence the results from eye to eye there must be added to these: age, refractive condition of eye, clearness of cornea and media of the eye, etc. Good test procedure requires that the variable influence of these factors shall as far as possible be eliminated by experimental control and that the influence of the remainder shall be corrected and compensated for by a suitable statistical treatment of the results.

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[1] C. E. Ferree and G. Rand, An instrument for testing the light and color sense with important features of standardization and control, *Amer. J. of Psychol.*, 1931, **43**, 275–287.

It is the purpose of the present paper to study the effect of size of stimulus on the light minimum and on the shape and length of the curve for dark adaptation for the central portion of the field of vision. Three possibilities may be noted as to the effect of increase in size of stimulus on the response of a sense organ.

(1) There is an increase in the total energy of excitation in direct proportion to the increase of the size of the stimulus. If it be conceived that the receptors act collectively one might expect an increase in the response of the sense organ in direct proportion to the increase in area of the stimulus, provided that the receptors included in the area stimulated are equally sensitive.

(2) If on the other hand it be conceived that the receptors act independently it might be expected that the intensity per unit area of stimulus, not the total intensity, would be effective in determining the response of the sense organ. In that case increase of area would not increase the power of the stimulus to arouse a response in the sense organ.

(3) A third view would be that increase of area is effective in arousing the response of a sense organ but that the effect is not directly proportional to the increase of area. In a somewhat extensive investigation of the response of the retina made in a number of studies, we have found this latter view to be correct within limits. That is, within a certain range of change an increase of size of stimulus increases the response of the sense organ but apparently not in direct proportion to the change in size. Even if the first view as stated above correctly represents the law of response of nervous structures, the conditions for its fulfillment would not be found in the retina. That is, it presupposes a uniform distribution of sensitivity over the receiving surface. Uniform sensitivity occurs over very limited areas in the retina.

The inclusion of dark adaptation in our problem adds still further facts for consideration. There is a great deal of variation in the function of dark adaptation from the center to periphery of the retina. In the fovea it is either entirely absent or very weak. Towards the periphery it first increases

for a short distance, then decreases. Further, the change is different in the different meridians. Over and above the effect of increase of area on the energy of response of the receptors as a factor in dark adaptation we have in addition, then, the inclusion of regions of different adaptability as the boundaries of the area stimulated are extended. An interesting pont in this connection is the relation of the sensitivity of the different parts of the retina to their susceptibility to change under stimulation, or their adaptability. This point will be studied in a later paper.

Method of Working

The study was made with the Ferree-Rand instrument for testing the light sense and light and dark adaptation. This instrument was devised for the control of all the factors which influence the results of the test for sensitivity to light and for making an accurate specification of the amount of light entering the eye in any determination.

Some of the features and advantages of the instrument are:

(1) It is easily portable, quick and convenient to operate and gives a high reproducibility of result.

(2) The amount of light entering the pupil of the eye, the density of light in the test field and the brightness of the test field can be measured directly and the instrument calibrated in terms of any or all of these measurements.

(3) The results are independent of changes in the size of the pupil, including the changes produced by the use of pilocarpin and other miotics.

(4) The results seem also to be independent of the condition of refraction of the eye. in so far as this affects the formation of the image.* This permits of a more direct examination of the powers of the retina than is ordinarily the case and adds greatly to the ease and convenience of making the examination. It also decreases the range of scatter of results in a group of observers,—a very important feature in the use of the instrument in diagnosis.

(5) Because of the small aperture in the eyepiece the results are further rendered independent of the influence of accommodation and distance of projection of the image. Distance of projection of the image has a small but appreciable effect on the determinations of retinal sensitivity.

(6) The size of the test field may be varied through a visual angle ranging from 0° to 36°. These changes may be quickly and conveniently made. The test field may also be made to have any shape that is desired.

(7) Provision is made so that the broken circle may be used as test object, in which case an objective check is had on the correctness of the judgment and an additional and very effective control of fixation is secured. It also can be used under conditions which test acuity at low illumination, or in fact at any level of illumination desired, with

* In a compilation of norms in a later study a small characteristic difference in the results was found for hyperopic eyes. Inasmuch as a difference was not obtained for myopic and astigmatic eyes, the explanation can probably be found in the condition of the sensorium, not in the image. The hyperopic eye is usually regarded as poorly developed.

the eye practically independent of errors of refraction insofar as these affect the formation of the image. The ability to render the eye independent of conditions of refraction is a very important feature in testing both the retina's power to sense light and to discriminate detail. With this instrument both the light and space sense can be tested under conditions which apparently render the test independent of the resolving power of the refractive system of the eye.

(8) A wide range of intensity of light is provided under quick and convenient control. The change of intensity is produced without change in the composition of the light.

(9) To insure the constancy of the efficiency of the lamp a checking standard is furnished, so that at any time the illumination of the test field for a given reading of the scale can be compared with that given by a standard lamp and a corrective change made in the operating current, if needed.

(10) The instrument can be used with equal facility in any state of adaptation, light or dark.

(11) All scales can be read by the examiner in the dark, and all adjustments of the instrument can be made without interfering with the state of adaptation of the patient.

(12) For the determination of the amount and rate of adaptation, a preëxposure field variable in size is provided, surrounding and including the test field.

(13) Either the light minimum or the light difference can be determined. The instrument has been designed, however, primarily for determining the light minimum.

(14) By the insertion of appropriate filters the instrument can be used just as effectively for testing the color sense and the achromatic sensitivity to colored lights as for testing the light sense.

(15) The instrument can also be used very effectively for the detection of small central scotomas for either light or color—scotomas of such a size as to be difficult of detection with the perimeter or tangent screen yet of sufficient importance to reduce acuity.

For the needs of the present study this instrument made possible the following features of control of conditions and of experimental variation: (1) all variable effects due to size of pupil, accommodation, distance of projection and errors of refraction were, as far as is possible, eliminated from the results; (2) the eye was pre-sensitized to a constant state of light adaptation before each series of observations was begun; (3) determinations of the light minimum were made with a constant degree of light adaptation and after fixed intervals of dark adaptation; (4) fixation was maintained with a very satisfactory degree of accuracy for each size of stimulus used; (5) the density of light or the amount entering the eye per unit area of the stimulus was measured directly; and (6) size of stimulus was varied from 0.75 to 15 degrees.

Eight sizes of stimulus were used, circular in shape, subtending visual angles of 0.75, 1, 2, 3, 5, 7, 10 and 15 degrees. Their diameters were respectively 0.98, 1.3, 2.6, 3.9, 6.6, 9.2, 13.1 and 19.8 mm. As an aid to the control of fixation for the larger stimuli, the test was always begun at an intensity at which the stimulus was visible, and the observer was instructed to look at its center. The light was then rapidly decreased until the stimulus was reported as no longer seen and then again increased to the threshold of visibility. Little or no difficulty was experienced in the control of the fixation for these larger stimuli as they extended into the more sensitive peripheral retina and there was no incentive for the eye to take an eccentric fixation. The stimulus was most clearly seen when its center was fixated. For the small stimuli which fell on the less sensitive central retina the case was different. As an aid to the direction of fixation

for these stimuli, the following device was employed. A circle subtending a suitable visual angle was outlined in the center of the field by drilling eight very small holes in the test plate. At the center of this circle was the stimulus aperture. The holes were drilled so that two of them occurred on a line bisecting the stimulus in the vertical plane and two bisected it in the horizontal plane. These four holes in particular served to direct fixation vertically and laterally to the exact center of the test plate and effectively prevented an eccentric fixation of the stimulus. To give these holes higher visibility than the stimulus, a neutral filter having a transmission of 3 percent was placed over the stimulus aperture.

As a still more sensitive control of fixation for the determination of central sensitivity in the darkened field of view we have often made use of the blind spot. For this, the blind spot was outlined by small luminous dots located just inside its edges. In this case the slightest movement of the eye in any direction causes one or more of the dots to become visible. It is obvious, however, that such a device is not feasible in an instrument designed for clinic use.

In order that each series of observations should be begun with the eye in the same state of sensitivity, the observer was required to sit for 20 minutes in a lighted room before the test was begun. The walls and ceiling of the room were of rough plaster painted flat white. The room was illuminated by a centrally located ceiling fixture of the indirect type, specially designed to be completely glareless. To secure a higher illumination of the reading page than was given by the ceiling fixture, a reading lamp was used, designed also to be completely free from glare. The horizontal component of illumination at the position of the observer was 16 ft c; the component normal to the reading page 11 ft c. At the end of this period the observer was seated in position in front of the instrument. To compensate for inequalities in the time which this allowed for recovery of the eye at different sittings and further to complete and standardize the pre-sensitization of the eye, the test was begun by requiring the observer to look for three minutes into the illuminated preëxposure field of the instrument. This field was circular in shape and subtended an angle of 36° at the eye. The density of light in the field was 17×10^{-8} lumens per sq. mm. This value is approximately 370 times the light minimum for the 1° stimulus and 944 times for the 5° stimulus at the beginning of the period of adaptation; and approximately 3,696 times for the 1° stimulus and 680,000 times for the 5° stimulus after 20 minutes of dark adaptation. At the end of the preëxposure period the plate containing the stimulus aperture was dropped into position and the light reduced to threshold intensity as quickly as possible by the interposition of a neutral filter of the proper density and the rapid adjustment of the distance of the lamp of the instrument until the observer reported the disappearance of the stimulus. The light was then quickly increased until the stimulus reappeared and the point of reappearance taken as the light minimum.

The light minimum was determined in this way at the end of the 3 minute preexposure period and at selected intervals until little or no change in sensitivity could be detected. The intervals used were 1, 2, 5, 10, 15 and 20 minutes. There was of course some slight variation in the time consumed in arriving at the final determination, but in general this time was no longer than 3 seconds. At the end of the 20 minute period of dark adaptation the value of the light minimum for the smaller stimuli showed little or no change, but for the larger stimuli it was still decreasing. To determine the course of adaptation until there was practically no further measurable change for these larger stimuli, the series was continued for 65 minutes for the 5° stimulus chosen as representative of the larger sizes.

The adaptation curves were determined several times for each size of stimulus. The reproducibility of result for the larger stimuli was high when allowance was made for irregularities introduced by 'streaming' which at times occurred when the determination of the threshold was being made. These obvious irregularities were not considered in arriving at the average curve for each size. For the smaller sizes of stimulus greater difficulty was encountered in taking and holding the fixation. With a reasonable amount of practice, however, this difficulty was overcome and a very satisfactory reproducibility of result was obtained. As might be expected too, the data for the first point of the curve for each of the sizes were found to be more variable than for the others, due to the fact that the exact time at which the determination is completed exerts a greater influence on the results obtained at the beginning of the period of adaptation when the rate of change of sensitivity is at its maximum. In conducting the test care was taken to reduce this variability to a minimum. The type of test instrument used was of great aid in this respect.

Results

The results obtained are given in Figs. 1 to 3 and Tables 1 to 5. In the figures and tables the effect of size of stimulus on the light minimum and on the amount and rate of dark adaptation is shown for sizes of stimulus subtending visual angles of 0.75° to 15° and for intervals of adaptation from 0 to 20 minutes.

TABLE 1

THE LIGHT MINIMUM FOR EACH SIZE OF STIMULUS AND EACH INTERVAL OF ADAPTATION

The unit used is 1×10^{-10} lumen entering the eye per sq. mm. of stimulus.

Size of Stimulus (Visual Angle)	Light Minimum (1×10^{-10} Lumen) for the Following Intervals of Adaptation						
	0 min.	1 min.	2 min.	5 min.	10 min.	15 min.	20 min.
0.75°	9.9	2.8	1.74	1.23	1.07	1.07	1.07
1.0°	4.6	0.87	0.63	0.52	0.46	0.46	0.46
2.0°	3.1	0.46	0.25	0.057	0.029	0.020	0.0139
3.0°	2.4	0.30	0.131	0.025	0.0091	0.0054	0.0034
5.0°	1.8	0.25	0.088	0.0175	0.0065	0.0037	0.0025
7.0°	1.52	0.235	0.087	0.0165	0.0058	0.0027	0.0017
10.0°	1.50	0.210	0.070	0.0150	0.0057	0.0023	0.0014
15.0°	1.50	0.172	0.070	0.0135	0.0051	0.0020	0.0011

In Table 1 are given the values of the light minimum for the different sizes of stimulus and the different periods of adaptation expressed in terms of 1×10^{-10} lumens entering the eye per square millimeter of stimulus.

In Fig. 1 the data are plotted to show the course of adaptation for the different sizes of stimulus. Light minimum is plotted on the vertical coördinate and time of adaptation on

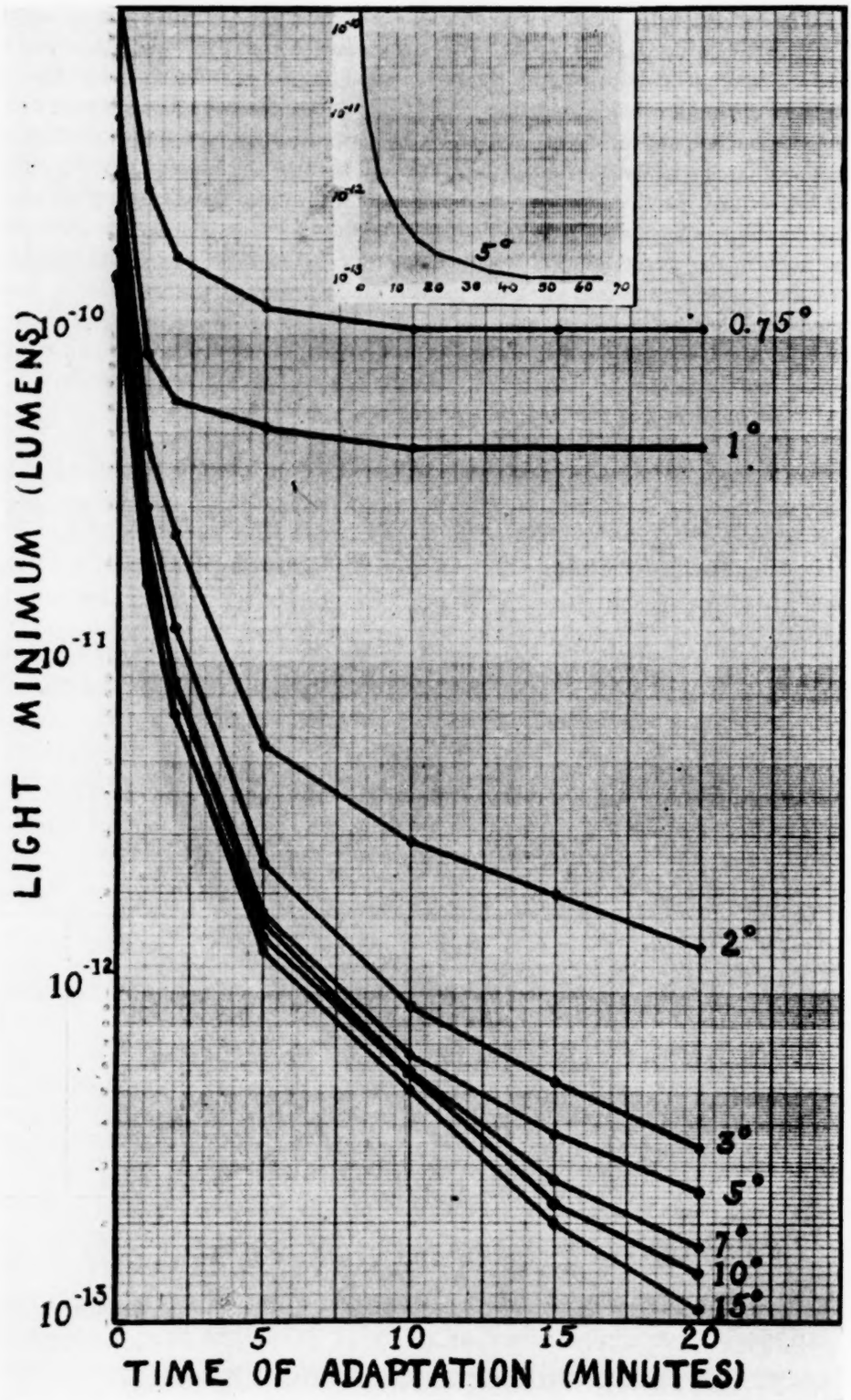

FIG. 1. Adaptation curves for different sizes of stimulus. Time of adaptation is plotted against light minimum for the following sizes of stimulus: 0.75, 1, 2, 3, 5, 7, 10 and 15° of visual angle. In the inset is given the curve for the 5° stimulus for 65 minutes of adaptation.

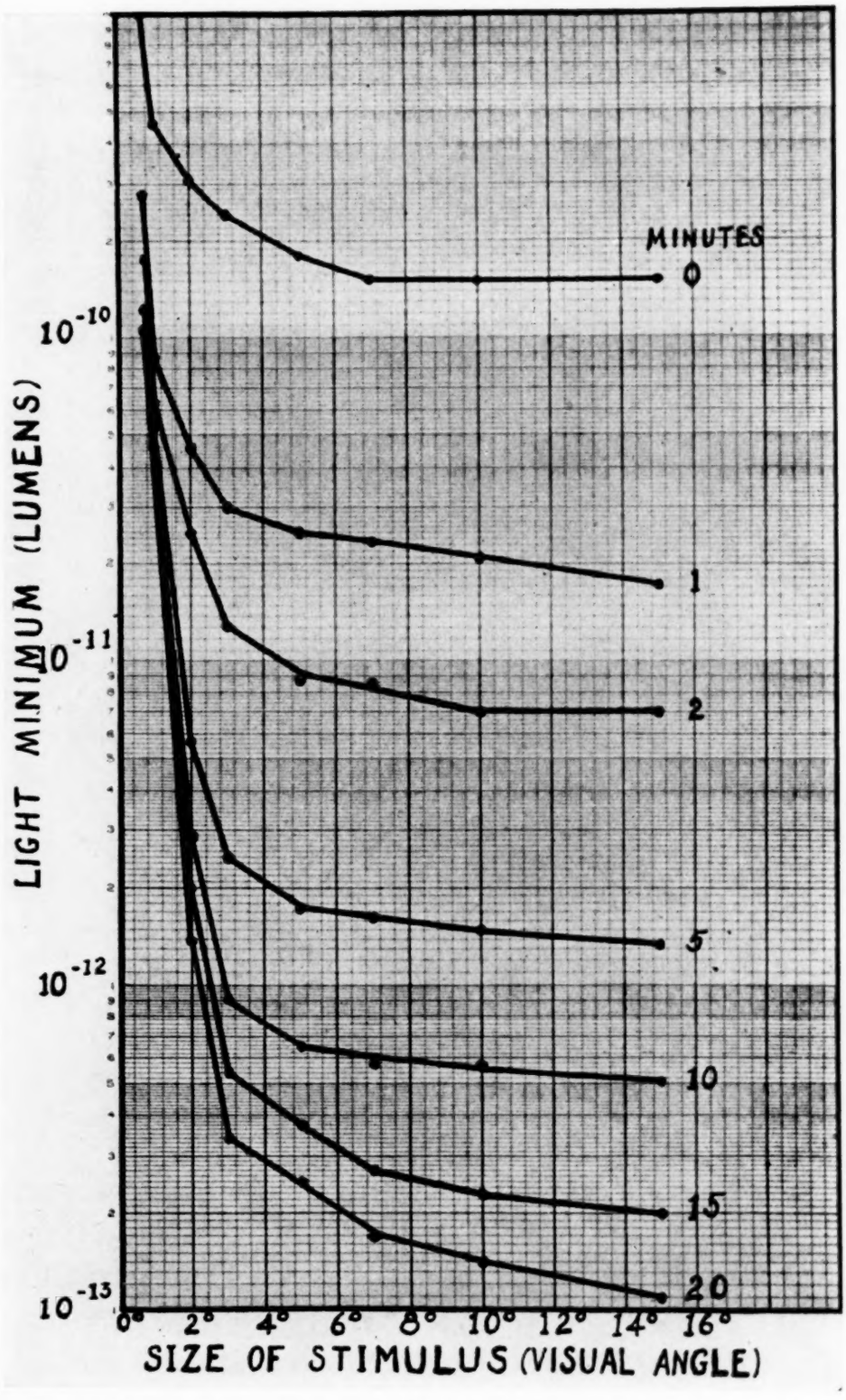

FIG. 2. Effect of size of stimulus on light minimum. Size of stimulus is plotted against light minimum for the following intervals of adaptation: 0. 1, 2, 5, 10, 15 and 20 minutes.

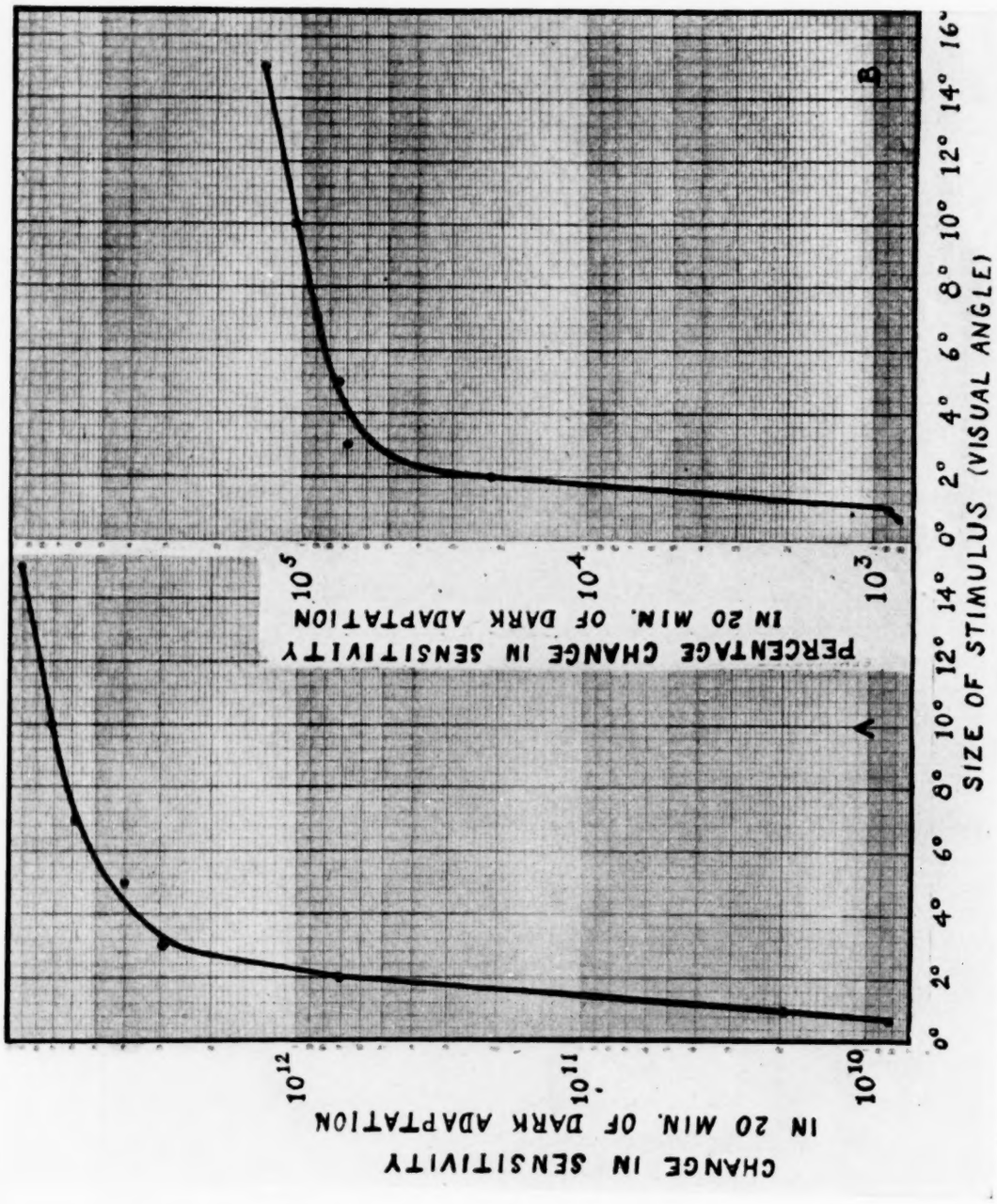

FIG. 3. Effect of size of stimulus on the amount of adaptation which occurred in 20 minutes. In *A*, size of stimulus is plotted against change in sensitivity from the beginning to the end of the adaptation period; and in *B*, against percentage change in sensitivity.

the horizontal coördinate. In this and the following figures the values for the vertical coördinate are plotted on a logarithmic scale. In the inset in Fig. 1 is given for comparison the curve for the 5° stimulus for an adaptation period of 65 minutes.

In Fig. 2 curves are given to show the effect of size of stimulus on the light minimum for each of the intervals tested during the course of adaptation. Light minimum is plotted on the vertical coördinate and size of stimulus expressed in degrees of visual angle on the horizontal.

Figure 3 shows the effect of size of stimulus on the amount of adaptation which occurred in twenty minutes. The amount of adaptation is expressed as the change in sensitivity [2] from the beginning to the end of the period of dark adaptation. In *A* of this figure change of sensitivity is plotted on the vertical coördinate and size of stimulus on the horizontal coördinate; and in *B*, percentage change in sensitivity on the vertical coördinate and size of stimulus on the horizontal. In computing percentage change the sensitivity at the beginning of the period of adaptation was taken as base.

The data presented may be summarized briefly as follows.

(1) There is an effect of size of stimulus on the light minimum for both the light and the dark-adapted eye. For light adaptation the effect is much less than for dark. The value of the light minimum for the 0.75° stimulus at the end of the period of light adaptation is, for example, 5.5 times as great as for the 5° stimulus, while it is 428 times as great after 20 minutes of dark adaptation.

(2) At the end of the period of light adaptation there is an effect of size of stimulus on the light minimum for sizes ranging from 0.75° to 7°. For sizes larger than this up to 15° there was no significant change in the light minimum. For the different intervals of dark adaptation, however, there is an effect for sizes ranging from 0.75° to 15°. The effect is most pronounced for increases in size up to 5°.

(3) There is a pronounced effect of size of stimulus also on the amount and rate of adaptation for the range of sizes noted

[2] Sensitivity is expressed as the reciprocal of the light minimum.

in (2). For the 5° stimulus the change in sensitivity in 20 minutes was, for example, 480 times as great as for the 0.75° stimulus. This increase of sensitivity with increase of size of stimulus over the range 0.75° to 5° was consistently present for each interval tested during the period of adaptation; that is, the curves for the different sizes of stimulus show progressively a greater amount of deviation from each other as the process of adaptation continues. For the larger sizes of stimulus up to 15° there was little significant change in the curves.

(4) The shape of the adaptation curve changes with increase of size of stimulus. For the smallest sizes used, 0.75° and 1° visual angle, there is a rapid decrease of the light minimum for the first 2 minutes and then only a very gradual change; that is, the first part of the curve is very steep and the knee occurs after two minutes of dark adaptation. For the remainder of the curves the slope is in general more gradual and the knee is less pronounced. While there is a sharp drop for the first 5–10 minutes, there is still an appreciable downward slope until the end of 20 minutes. In case of the curve for 5° for which the adaptation was continued for 65 minutes, the more pronounced drop in sensitivity continued until 35 minutes had elapsed. For 10 minutes beyond this there was some decrease in the light minimum and then no further change for the next 20 minutes.

In order to show in numerical terms the effect of size of stimulus on the light minimum at different intervals during the course of adaptation and on the amount and rate of adaptation, Tables 2 to 4 have been prepared. The first of these effects is shown in Table 2. In this table is given for each interval tested the percentage decrease in the light minimum per sq mm increase in area of stimulus for each successive variation of size employed. Column 1 gives the ranges of sizes compared expressed in degrees of visual angle; column 2 the ranges of areas of stimuli compared; and columns 3 to 9 the values of percentage decrease in light minimum per sq mm increase in area of stimulus for the following intervals during the course of adaptation: 0, 1, 2, 5, 10, 15 and 20 minutes. In

TABLE 2

THE PERCENTAGE DECREASE IN LIGHT MINIMUM PER SQ. MM. INCREASE IN AREA FOR GIVEN RANGES OF SIZE OF STIMULUS

This percentage decrease is shown at the end of the period of light adaptation and at selected intervals in the course of dark adaptation. In computing percentage change, the light minimum at the beginning of the range was taken as base.

Range of Size of Stimulus (Visual Angle)	Range of Area of Stimulus (sq. mm.)	Percentage Decrease in Light Minimum per sq. mm. Increase in Area of Stimulus						
		0 min.	1 min.	2 min.	5 min.	10 min.	15 min.	20 min.
0.75°– 1°...	0.75– 1.35	90.1	114.2	105.8	95.9	96.8	96.8	96.8
1° – 2°...	1.35– 5.39	8.1	11.7	11.0	21.9	23.1	23.7	24.2
2° – 3°...	5.39– 12.13	3.4	5.2	7.1	8.4	10.5	11.1	11.1
3° – 5°...	12.13– 33.70	1.2	0.8	1.4	1.3	1.3	1.4	1.2
5° – 7°...	33.70– 66.04	0.5	0.2	0.03	0.12	0.33	0.83	0.99
7° –10°...	66.04–135.19	0.02	0.10	0.27	0.13	0.03	0.21	0.26
10° –15°...	135.19–306.67	0.00	0.07	0.00	0.04	0.04	0.05	0.07

computing these percentages, the value of light minimum for the smaller size of stimulus was taken as base. A comparison of the values given in the vertical columns shows the percentage change in threshold per unit increase in area of stimulus at each of the above intervals during the course of adaptation.

The table shows that for all the extrafoveal sizes of stimulus the effect of increase of size on the light minimum is in general greater at the end than at the beginning of the period of dark adaptation; that is, as adaptation continues and the sensitivity of the eye is increased the effect of size, as might be expected, becomes greater. This is most pronounced for stimuli ranging from 1° to 3° visual angle, in which cases there is from three to four times more effect of increase of area at the end than at the beginning of the adaptation period. For stimuli ranging from 0.75° to 1° the differential effect of increase of area is approximately the same for each interval of adaptation. Decrease in light minimum per sq mm increase in size of stimulus may be considered negligible for increases greater than 5° visual angle.

In Table 3 is shown the effect of size of stimulus on the total amount or range of adaptation. In column 1 is given the size of stimulus; in column 2 the initial sensitivity, *i.e.*, the sensitivity at the beginning of the period of dark adaptation; in column 3 the final sensitivity; and in column 4 the amount

TABLE 3

THE CHANGE IN SENSITIVITY OR THE AMOUNT OF ADAPTATION WHICH OCCURRED IN 20 MINUTES FOR DIFFERENT SIZES OF STIMULUS

Size of Stimulus (Visual Angle)	Initial Sensitivity (1×10^{10})	Final Sensitivity (1×10^{10})	Amount or Range of Adaptation (1×10^{10})	Ratio of Final to Initial Sensitivity (1×10^{10})
0.75°	0.10	0.93	0.83	9.25
1.0°	0.22	2.17	1.96	10.00
2.0°	0.32	71.94	71.62	223.01
3.0°	0.42	294.12	293.70	705.83
5.0°	0.56	400.00	399.44	719.94
7.0°	0.66	588.24	587.58	894.11
10.0°	0.67	714.29	713.62	1071.37
15.0°	0.67	909.09	908.43	1363.57

or range of adaptation expressed as a ratio of final to initial sensitivity. This table shows that the total amount of adaptation in 20 minutes increases with increase in area of stimulus, particularly when foveal sizes are compared with extrafoveal. For example, the range of adaptation for the 1° stimulus was twice that of the 0.75°; for the 2°, 35 times, and for the 5°, 200 times that of the 1°; for the 5°, 5 times, and for the 15°, 13 times that of the 2°. The ratio of final to initial sensitivity for the two foveal stimuli was approximately the same. For the 2° size it was, however, approximately 25 times, and for the 5°, approximately 80 times that for 1°; and for the 5°, approximately 3 times, and for the 15°, 6 times that of the 2°.

TABLE 4

THE PERCENTAGE RATE OF INCREASE IN SENSITIVITY PER MINUTE AT THE END OF THE PERIOD OF LIGHT ADAPTATION AND AT GIVEN INTERVALS DURING THE COURSE OF DARK ADAPTATION

This percentage rate of increase is shown for different sizes of stimulus. In computing percentage change, the sensitivity at the beginning of the interval was taken as base.

Interval of Adaptation	Percentage Increase in Sensitivity per Minute of Dark Adaptation. Size of Stimulus (Visual Angle)							
	0.75°	1°	2°	3°	5°	7°	10°	15°
0–1 min.	256	428	573	675	862	546	614	772
1–2 min.	61	38	84	129	184	170	200	146
2–5 min.	14	7	113	141	134	142	122	140
5–10 min.	3	3	19	35	34	37	33	32
10–15 min.	0	0	9	14	15	23	30	31
15–20 min.	0	0	9	12	10	12	13	16

In Table 4 is shown the rate of adaptation for the different sizes of stimulus used. In this table is given for each size the percentage increase in sensitivity per unit of time through the various intervals tested in the course of dark adaptation. Column 1 gives the intervals of dark adaptation compared, and columns 2 to 10 the percentage increase in sensitivity per minute of adaptation for stimuli subtending the following visual angles respectively: 0.75°, 1°, 2°, 3°, 5°, 7°, 10°, and 15°. In computing these percentages the value of sensitivity for the smallest interval of adaptation employed was taken as base. A comparison of the values given in the vertical column shows the percentage change in sensitivity per minute increase in adaptation for each of the above sizes of stimulus.

This table shows that for all stimuli by far the greatest rapidity of recovery of sensitivity occurs in the first minute. For the 0.75° and 1° stimuli there was very little recovery per minute after five minutes of adaptation; for the 2°, 3° and 5° stimuli, comparatively little after fifteen minutes; but for the 7°, 10° and 15° stimuli there was still an appreciable increase in sensitivity per minute of adaptation between 15 and 20 minutes.

The data were further analyzed with reference to Piper's law of the relation between size of stimulus and light minimum.[3] This law, which was determined for dark adaptation only and for stimuli located eccentrically, states that light minimum $\times \sqrt{\text{area}}$ of stimulus is a constant. In Table 5 are given the products of light minimum and $\sqrt{\text{area}}$ of stimulus for our data which were obtained, it will be remembered, for stimuli located centrally and under varying conditions of adaptation from light to dark. The table shows that this product tends to increase with size of stimulus under conditions of light adaptation, and to approach a constant value as the adaptation period is prolonged for sizes of stimulus ranging from 3° to 15°. For sizes ranging from 0.75° to 2°, however, it decreases for the intervals of dark adaptation between 2 and 20 minutes. It is probable that with a longer period of adap-

[3] Piper, H., Über die Abhängigkeit des Reizwertes leuchtenden Objekte von ihrer Flächen- bzw. Winkelgrösse, *Z. f. Psych. u. Physiol. der Sinnesorgane*, 1903, **32**, 98–113.

tation than the 20 minutes used in this study, Piper's law would have been more nearly verified in our results for stimuli ranging from 3° to 15°. For stimuli smaller than 3° the comparative insensitivity to light of the foveal region is probably a greater factor in the results than it is for larger sizes. For these smaller sizes the light minimum apparently follows some other law or laws of response.[4]

TABLE 5

THE PRODUCT OF LIGHT MINIMUM × $\sqrt{\text{AREA}}$ OF STIMULUS FOR EACH SIZE OF STIMULUS AND EACH INTERVAL OF ADAPTATION; AND THE PRODUCT OF LIGHT MINIMUM × $\sqrt[4]{\text{AREA}}$ OF STIMULUS FOR EACH SIZE AT THE END OF THE PERIOD OF LIGHT ADAPTATION

Size of Stimulus (Visual Angle)	Light Minimum × $\sqrt{\text{Area}}$ of Stimulus							Light Minimum × $\sqrt[4]{\text{Area}}$ of Stimulus
	Light Adaptation	1 min. Dark Adaptation	2 min. Dark Adaptation	5 min. Dark Adaptation	10 min. Dark Adaptation	15 min. Dark Adaptation	20 min. Dark Adaptation	Light Adaptation
0.75°....	8.60	2.44	1.51	1.07	0.93	0.93	0.93	9.2
1.....	5.34	1.01	0.73	0.60	0.53	0.53	0.53	5.0
2.....	7.19	1.07	0.58	0.25	0.067	0.047	0.032	4.7
3.....	8.35	1.04	0.46	0.087	0.032	0.019	0.012	4.5
5.....	10.44	1.45	0.51	0.102	0.038	0.021	0.015	4.3
7.....	12.37	1.91	0.71	0.135	0.047	0.022	0.014	4.3
10.....	17.45	2.44	0.81	0.175	0.064	0.027	0.016	5.1
15.....	26.26	3.01	1.23	0.236	0.089	0.035	0.019	6.3

Analysis of our data for light adaptation shows that the light minimum varies approximately as the fourth root of the area of the stimulus for sizes ranging from 1° to 7°. For sizes larger than this up to 15°, it will be remembered, there was no change in the light minimum. Column 9 of Table 5 gives the product of light minimum × $\sqrt[4]{\text{area}}$ of stimulus for the results of light adaptation.

For the intervals of adaptation between 0 and 20 minutes, no exponential relation was found which held for any considerable range of size. The interplay of factors: light and dark adaptation, foveal and extrafoveal areas of stimulation,

[4] Since our experimental conditions included only two stimuli of foveal area, no attempt was made to analyze the data in terms of Ricco's formula (light minimum × area of stimulus is a constant) which was derived for stimuli of foveal size under conditions of light adaptation.

apparently resulted in a more complex relationship between light minimum and area of stimulus.

Conclusion

Size of stimulus is an important factor in the retina's response to colorless light for the ranges of size that are apt to be used in tests for sensitivity or adaptation. All norms or diagnostic scales for either of these functions must, therefore, be compiled with a careful standardization of this factor. With reference to systematic and theoretical conceptions it is found that increase in size is effective in arousing the retina's response for both foveal and extrafoveal sizes of stimulus and under conditions of both light and dark adaptation. A satisfactory quantitative formulation of this effect has not been found to be possible. Certain tendencies, however, are shown. In light adaptation, for example, for sizes of stimulus ranging from 1° to 7° sensitivity tends to increase as the fourth root of the area of the stimulus; in dark adaptation for stimuli ranging from 3° to 15° the tendency is to vary as the square root of the area. The effect on sensitivity for the range of sizes used in our experiments is a true effect of size, not merely the inclusion of regions of greater sensitivity within the area tested. Results in proof of this will be given in a later paper.

(Manuscript received July 3, 1933)

THE CONSTANCY OF HYPOCHROMATIC VISION [1]

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Introduction

In a report before the English Board of Trade in 1890, the Marquis of Salisbury said that he was convinced color-blindness was capricious; on some days he was much more color-blind than on others. It is now quite certain that he did not mean that his guess for a certain color was good on one day and poor on another—as Collins remarks, the color-weak have a definite system of color sensations and a definite nomenclature to describe these sensations.[2] The point he wished to develop was the fluctuation or inconsistency of this system from day to day. It was the purpose of this investigation to discover whether or not the color systems of those with hypochromatic vision varied from time to time over a period of more than twenty-six weeks.[3] The problem has a formal resemblance to the controversy about the constancy of the I.Q. since both issues raise the question of the validity of a diagnosis of a permanent condition from a single testing series. It is a misfortune that most of our older laboratory measures have not benefited from the existence of statistical technique which has brought the paper-and-pencil tests to their present status.

Apparatus and Procedure

One thousand and one male students at the Pennsylvania State College were examined with the Ishihara Color Test and fifty-eight defective subjects were located (5.8 percent). Two weeks later 145 female students were given the same test resulting

[1] This topic was suggested by Professor George W. Hartmann, under whose direction the study was performed.

[2] Collins, M., *Color-Blindness* (New York, Harcourt, Brace & Company, Inc., 1925), p. 214.

[3] The term 'hypochromatic' vision is used to denote lessened color sensitivity, and is to be preferred to terms which suggest a definite degree or classification.

in the identification of two subjects (1.3 percent). Only those subjects with congenital weakness were included in this work since it is well recognized that an acquired weakness varies with the kind and degree of causation. A normal group of eighteen male students and two females was used as controls. The Ishihara Test was selected as the criterion test after considering the results of other investigators.[4] It was necessary for the subject to read at least fourteen of the sixteen plates in the book to pass the test. Other visual tests also given at the same time indicated that 55 percent of the control group had vision less than 20/20 in both eyes or other visual defects as compared to 34 percent of the test group. Lessened color sensitivity seemed to be definitely unrelated to deficient vision.

Immediately after the selection of these groups a battery of recognized tests was collected. This consisted of the Ishihara Color Book, the Nagel Color Cards, Holmgren Yarns and a color rotator, containing a tripartite disc of red, green and blue, 18 mm in diameter with a smaller concentric disc 13 mm in diameter. The outer and inner discs could be turned to allow a match to be made between them.

Table I shows the inter-correlations of these tests, with the exception of the color rotator that was used for the formation of equations.

TABLE I

INTER-CORRELATIONS AND P.E. VALUES OF THE BATTERY OF COLOR TESTS

Test	*r*	P.E.
Control Group (N 20)		
Nagel Test, parts *A* and *B*	.9269	±.013
Ishihara and Nagel A	.7265	±.074
Ishihara and Holmgren	.6478	±.091
Nagel A and Holmgren	.8421	±.046
Test Group (N 50)		
Nagel Test, parts *A* and *B*	.5781	±.067
Ishihara and Nagel A	.4771	±.077
Ishihara and Holmgren	.5176	±.073
Nagel A and Holmgren	.5680	±.067

This table is fairly indicative of the homogeneity of the test battery. There is not a great difference between the correlations of the Ishihara and Nagel A Tests and the Ishihara and Holmgren Tests. This is quite significant in that the Ishihara Test was constructed upon the pattern of the Nagel Test and was considered to be the most acute of the entire battery. It seems probable that these tests do not all measure exactly the same thing for that would demand higher *r*'s than were actually obtained. That slightly different chromatic functionings are involved in each test seems probable but uncertain.

The tests were arranged upon the two ends of a laboratory table 230 mm long and 70 mm wide covered with gray paper. The Ishihara, Nagel and Holmgren Yarns were placed at one end and the color rotator at the other. The former were illuminated by a 100 watt, 115 volt daylight mazda lamp hung thirty mm from the exact center of the table, while the color mixer was placed at a definite angle sixty-two mm from the position of the subject and illuminated by two similar lamps focused upon its center. These lamps were obtained from the General Electric Company together with a

[4] Terman, S., A new classification of the red-green blind, *American Journal of Psychology*, 1929, 41, pp. 237–251, and Garth, T., Color-blindness among Indians, *Science*, 1930, 71, p. 467.

mortality curve indicating the per cent decrease in intensity per 1000 hours of continuous burning. The lamps burned 129 hours including a twenty-four hour seasoning period and lost approximately 0.25 per cent of their initial intensity. A curve indicating the relative energy in wave lengths within the visible spectrum showed the lamps to be about twice as strong in blue or violet as red or orange when the white line was plotted.

The illumination and position of the tests were kept constant for the three examinations. Twenty-one weeks passed between the testing of the median subjects of examinations one and two, while five weeks passed between the testing of the median subjects of examinations two and three. Subjects were tested individually between the hours of seven and ten P.M. In giving each examination (save the color mixing), the subject was required to stand firmly on his feet; the object of such a requirement being to keep the distance between the test and the subject's fovea in constant proportion so that the visual angle subtended would include about the same part of the retina at each examination. A sitting posture appears to be more conducive to variation. The order of examination was the Ishihara, Nagel, Holmgren and finally the color mixtures. When the last test was used, the illumination of the other tests was extinguished and they were covered with gray paper similar in intensity to the background. The subjects were required to sit at a constant distance from the discs. An ascending threshold technique was used in equating one color with another. The sectors were set at degree combinations below the one normally needed for a good matching and were cleared of all shadows. Instructions were then given to focus his eyes on a certain portion of the discs; to try to remove any color he could see, to get an absence of color or gray and to match the discs in this state—a lengthy task.

The scoring of the results was based upon unity or 100 as a maximum for each test, and in the evaluation of certain of these tests a comparison was made with the control group. This was the case of the Holmgren Yarns where the quality and number of matches of the normal group were used as a basis for evaluating the test group. If a similar array were made by the test group, it was considered correct and evaluated at forty percent for the rose skein, forty for the green and twenty for the red. In color matching the number of degrees of red, green and blue equating black and white was recorded. Red and green were then set in ratios to each other, *i.e.*, the red divided by the mean of the green and vice versa.

Results

When the results of the three examinations were graphed for comparison, three facts became apparent: (1) the absence of a normal distribution of hypochromatic vision; (2) the distinct position of the control group as compared with the test group, and (3) the coincidence of one examination with another. The absence of the normal curve in all the tests reënforces the opposition to von Kries's assumption of macular pigmentation as the cause of hypochromatic vision. If this were so, color-weakness should have the same incidence as other somatic characteristics. This absence of normal distribution in the color mixing test also renders dubious Selig

Hecht's theory that sensitivity to intensity of illumination varies with the statistical distribution of receptors. Now, if that were true, and since our color rotator is supposed to measure luminosity rather than hue, the ratios of this test ought to be distributed approximately in the form of a normal curve for the control group. E. Freeman has also shown the weakness of Hecht's view by the translation method.[5]

This same lack of definite form in distribution suggests the impossibility or at least the inexpediency of systematizing color sensations into two or more classes. Professor Hayes and Dr. R. A. Houston have also arrived at the decision that a strict classification of color defectives is necessarily defective.[6] There are probably numerous transitional cases between normality and total color-blindness.

The positions of the control group and the test group indicate a wide difference between the means of each, or the degree to which the color-weak group differ from the normal. The probabilities against any true overlapping of the two groups are enormous. The coincidence of the means and the graphs of one examination with another shows that hypochromatic vision is fairly stable for the group as a whole from one period to the next; individual shifts in position, of course, can not be gauged by this method, but must be determined from the size of the correlations between the successive examinations.

Table II contains the mean values and standard deviation values of the tests used in the control group:

TABLE II

THE MEANS AND STANDARD DEVIATION VALUES OF TESTS IN THE CONTROL GROUP (N 20)

Test	No.	Mean	S.D.
Ishihara	20	96.25	1.005
Nagel Test, part *A*	20	80.25	22.12
Nagel Test, part *B*	20	68.75	9.92
Holmgren	20	64.45	12.69
Color mixing ratio: Red	20	1.65	.95
Green		.60	.169

[5] Freeman, E., Anomalies of visual acuity, *Amer. J. of Psychol.*, 1930, **62**, 287–294.

[6] Collins, Mary, *Color-Blindness*, N. Y.: Harcourt, Brace, 1925, pp. 17 and 224.

The standard deviation values of the Nagel Test, part *A*, and the Holmgren were high, indicating a great scatter of scores from the means of each. The extreme scatter in the Nagel Test might be accounted for by the number of negative scores that were produced by the omission of certain plates. It also occurs in the test group (cf. Table III).

The next table is a cumulative record of the results of three distributed repetitions of each test for the experimental group.

It will be observed from this table that the means of almost every examination are similar. The only exceptions to this generalization are the means of examinations one and

TABLE III

A Cumulative Record of Examinations One, Two and Three of Each Test in the Test Group

Test	No.	Mean	S.D.	r	P.E.	Standard Error of Mean	Standard Error of the Difference between the Means	Chances in 100 that the Obtained Score is Greater than Zero
Ishihara Test,								
Exam. 1.....	50	15.12	26.13			3.69		
Exam. 2.....	50	16.00	33.79	.7265	±.047	4.77	3.2	61
Exam. 1.....	50	15.12	26.13			3.69		
Exam. 3.....	50	16.00	26.40	.7557	±.071	3.73	2.5	64
Exam. 2.....	50	16.00	33.79			4.77		
Exam. 3.....	50	16.00	26.40	.7167	±.048	3.73	3.3	50
Nagel Test, *A*,								
Exam. 1.....	50	28.2	92.37			13.06		
Exam. 2.....	50	25.2	106.22	.7557	±.042	15.02	9.9	63
Exam. 1.....	50	28.2	92.37			13.06		
Exam. 3.....	50	35.2	92.94	.7557	±.042	13.14	9.6	76
Exam. 2.....	50	25.2	106.22			15.02		
Exam. 3.....	50	35.2	92.94	.7069	±.047	13.14	10.9	81
Nagel Test, *B*,								
Exam. 1.....	50	72.5	96.28			13.61		
Exam. 2.....	50	74.0	86.81	.6971	±.051	12.27	10.2	56
Exam. 1.....	50	72.5	96.28			13.61		
Exam. 3.....	50	72.5	96.28	.3933	±.084	13.61	14.9	50
Exam. 2.....	50	74.0	86.81			12.27		
Exam. 3.....	50	72.5	96.28	.6577	±.056	13.61	10.7	55

TABLE III—(*Continued*)

Test	No.	Mean	S.D.	*r*	P.E.	Standard Error of Mean	Standard Error of the Difference between the Means	Chances in 100 that the Obtained Score is Greater than Zero
Holmgren Test,								
Exam. 1.....	50	31.79	36.71			5.19		
Exam. 2.....	50	27.92	37.01	.6180	.061	5.23	3.9	84
Exam. 1.....	50	31.90	36.71			5.19		
Exam. 3.....	50	28.30	33.65	.6379	.059	4.75	4.2	81
Exam. 2.....	50	27.92	37.01			5.23		
Exam. 3.....	50	28.30	33.65	.7654	.059	4.75	3.4	68
Color Mixing Test,								
Exam. 1 Red .	50	1.44	.66			.093		
Green	50	.68	.36			.050		
Exam. 2 Red .	50	1.43	.44	.6971	.041	.062	.066	56
Green	50	.70	.38	.5981	.064	.053	.047	66
Exam. 1 Red .	50	1.44	.66			.093		
Green	50	.68	.36			.050		
Exam. 3 Red .	50	1.41	.47	.6280	.065	.060	.072	42
Green	50	.70	.33	.6379	.059	.046	.034	73
Exam. 2 Red .	50	1.43	.44			.062		
Green	50	.70	.38			.053		
Exam. 3 Red .	50	1.41	.47	.6676	.056	.066	.053	65
Green	50	.70	.33	.5277	.072	.046	.048	50

three and two and three of the Nagel Test, part *A*. Even here the differences of seven and ten points are not large enough to be significant when we consider that the position of the cards, soiling, fading, etc., would allow the subject in examination three, the last to be given, to have a higher score. The standard deviation values are high for every test, particularly the Nagel Tests. This is to be expected from the known incidence of color abnormality. Male subjects generally scatter to the two extremes. If a comparison could be made with a sufficient number of women the wide scatter would be brought out graphically since the females usually group about the mean more closely.[7]

The correlations between examinations over the period

[7] Collins, M., The Rayleigh Color Equations With Rotating Discs, *Brit. J. of Psychol.*, 1929, **20**, 387–393.

of twenty-six weeks are not extremely high, but are very consistent throughout, indicating comparative stability from one occasion to another. Examinations one and three of the Nagel Test, part *B*, have a low correlation. A protocol check revealed higher individual scores on examination three. This might be explained by the short period between examinations two and three enabling the subject to remember the four cards of the group, two of which are very easy even for extreme cases. The correlations between the same tests given at different intervals are generally higher than correlations between different color tests administered at the same time (*cf.* Tables I and III).

The differences in hue, intensity and saturation of the several parts of each test would not allow accurate split-reliability measures, but an attempt was made indirectly to unearth the individual consistency. Graphs were plotted indicating the maximal and minimal standard deviation for the individuals in the control and test group. The highest deviation was 1.75 sigma. In no examination, except the color mixing, did any individual in the test group exceed the deviation of the normal. The exception might be indicative of the unsuitability of equations for measurement. They probably reveal color inequality rather than an actual measurement of weakness.

Throughout the work it was recognized that slight inconsistencies would occur between one examination and the next due to physiological conditions of the subject which it was impossible to control, and environmental changes. However, the aim of this study was to discover whether the deviation between one examination and the next was great enough to signify an actual change in the color systems of those with hypochromatic vision. Apparently, it is not.

Table IV shows the percentages of errors occurring with red and green as stimuli. It is based upon the assumption that the parts of each test are approximately the same in hue, intensity and saturation. The number of red and green stimuli in each test was not equal. In some tests there were a greater number of the red stimuli and in other tests a greater

number of green. These were made equivalent by multiplying the lesser number of stimuli by the necessary multiple. The number of errors in each test was then translated into percentages.

TABLE IV

PERCENTAGES OF RED AND GREEN ERRORS IN THE NAGEL *A* AND *B*, ISHIHARA AND HOLMGREN TESTS

Test	Red		Green	
	No.	Percent	No.	Percent
Control Group (initial test only):				
Ishihara	0	0	0	0
Nagel *A*	12	.12	37	3.70
Nagel *B*	8	.08	1	.02
Holmgren	47	.47	94	1.88
Test Group:				
Examination 1				
Ishihara	387	3.87	194	4.36
Nagel *A*	274	2.74	131	13.10
Nagel *B*	28	.28	13	.26
Holmgren	468	4.68	304	6.08
Examination 2				
Ishihara	390	3.90	185	4.16
Nagel *A*	268	2.68	124	12.40
Nagel *B*	31	.31	21	.42
Holmgren	384	3.84	431	9.62
Examination 3				
Ishihara	363	3.63	189	4.25
Nagel *A*	226	2.26	116	11.60
Nagel *B*	31	.31	24	.48
Holmgren	281	2.81	415	8.30

The percentages of error in response to green stimuli are almost always in excess of the red. The only exception is the Nagel Test *B* in the control group and in examination one of the test group. In the other tests the percentages of green error range from less than twice as many up to thirty times the percentages of the red, as is the case of the Nagel *A* Test in the control group. This fact may have some bearing upon current color theories.

DISCUSSION AND CONCLUSIONS

It is to be regretted that the control group could not be secured for a final examination at the same time as the test

group. If this had been done, it would have been possible to compare the correlations of the two groups over the period of twenty-six weeks and to point out the differences in consistency between the two during these periods. As the study now stands, its value lies in showing the progress of the test group alone. However, if we assume the color vision of the normal group to be nearly perfect as measured by our tests and also assume this to vary but little due to physiological and physical conditions when measured by the same tests, some notion of the comparative stability of the test group can be obtained. So far as we know now, a subject who could pass the battery of tests at the beginning of the twenty-six weeks could also make the same score at the conclusion. But this still lacks experimental confirmation. Negatively, we may say that a person who is diagnosed as color-weak will probably always remain such.

That there should be so many more errors with green as a stimulus seems to indicate that the metabolic processes of anabolism and catabolism required by the Hering theory do not give similar results. According to this theory, color-weakness should be of a dual nature—both to red and green. Now, if the influences of inequality in hue, intensity and saturation be discounted, it would seem probable in the distribution of errors in a group of fifty that there should be almost an equal number of each kind. Actually this is not so—evidence that tends to cast doubt on the Hering explanation.

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THE INFLUENCE OF AN INCREASE IN MUSCULAR TENSION ON MENTAL EFFICIENCY

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Introduction

The question of the relation of muscular tension to mental efficiency has interested investigators for many years. The problem is directly related to the motor theory in the development of which Washburn (**21**) and Holt (**8**) have played an important role. Langfeld has given an excellent review of this motor theory in two recent articles (**12**, **13**).

The specific problem which has been most often attacked is whether or not there is an increased tension in the body during mental work. The mass of evidence gives a positive answer to this question. There are several exceptions, however, notably in the work of Loeb (**15**), Lehmann (**14**), and R. MacDougall (**16**). They found a decrease in muscular tension accompanying mental activity. Bills (**1**) summarizes the work which has been done in this field.

The above experiments are an indirect approach to the present investigation. They indicate that an increase in tension is associated with mental work, but they do not show the role which this tension plays. There are several possible answers to the latter question. The tension may be a beneficial factor, *i.e.*, an increase in tension may increase mental efficiency. It may be merely an added obstacle which the subject must overcome. Or it may be a passive factor which neither helps nor hinders.

Bills (**1**) has attacked this problem directly. He used two hand dynamometers as the means of producing a definite increase in tension. The mental work consisted in learning lists of nonsense syllables, learning lists of paired associates of meaningful words, adding columns of 20 digits, and naming letters. He found that muscular tension of this form and amount increases the efficiency of mental work.

In a later experiment, Bills (**2**) studied the effect of tension on stylus maze learning and on free and partially controlled associational processes. In the maze learning, those subjects who used the most tension learned most rapidly and made fewest errors. In the study of associational processes, hand dynamometers were used as the means of producing an increase in tension. In the partially controlled association, the responses given during the tension period were found to be superior to those given during the normal period. In the free association tests there was no consistent difference between the two conditions.

The work of Jacobson on *Progressive Relaxation* (**9**) is also of interest in connection with the present problem. After carefully training his subjects to relax until they were more completely relaxed than one ordinarily is in sleep, he found that in this relaxed state no mental work was possible. Even imagery disappeared. Jacobson's work seems to indicate that a certain amount of tension is necessary before mental activity can occur.

The problem of our investigation was to determine the effect of an increased tension in the right leg upon the subject's ability to solve short arithmetical problems. The present experiment differed from Bill's study in two important respects. First, in the present experiment the tension was increased in a different part of the body; and second, we used a more complex type of mental activity.

Apparatus

The apparatus included a pedal similar to the foot brake pedal of an automobile. This pedal was in a fixed position on the floor under a table. The subject was seated on one side of the table and the experimenter was on the other side. They were screened from one another's view. The subject pushed on the pedal with his right foot against the tension of two strong coil springs. On the experimenter's side of the table, the pedal was attached by means of cord and pulleys to a lever which indicated on a scale the amount of pressure in pounds exerted on the pedal by the subject. A weight at the other end of the cord kept the cord taut at all times. The subject was required to maintain a pressure between 25 and 40 pounds during the tension trials. There were two light signals on the subject's side of the table and when one of these lights flashed on, it indicated to the subject that the pressure was too slight, and when the other light flashed on, it indicated to the subject that the pressure was too great. As long as the subject maintained a pressure between 25 and 40 pounds, neither light came on.

Material

The material used for the mental work consisted of 48 short arithmetical problems which had been selected from a number of intelligence tests. The problems were of different types and of varying degrees of difficulty. They were given to about 15 subjects in a preliminary experiment to determine their suitability for the present experiment.

Procedure

Eighteen university students, 6 men and 12 women, were used as subjects. Among the subjects there were two freshmen, two sophomores, eight juniors, four seniors, and two graduate students. Each subject came for four experimental periods at irregular intervals. The majority of the subjects came twice a week and completed the experiment in two weeks. One subject completed the experiment in four days; and for another subject a period of two months elapsed between her second and third appearances.

During the first experimental period, the subject attempted to solve 24 problems. Half of the subjects used the odd-numbered problems under normal conditions and the even-numbered problems under tension conditions. The other half of the subjects used the even-numbered problems under tension and the odd-numbered problems under normal conditions. The subject maintained approximately the same posture throughout the experiment. He rested his foot on the pedal during the normal condition, but did not push. During the second experimental period, the subject attempted to solve 24 additional problems following a procedure similar to that in the first experimental period. In the third period, he repeated the 24 problems used during the first period, but on this occasion each problem was worked under a condition that was the opposite of that used in the first period. In the fourth period, the subject repeated the problems of the second period, but the procedure with each problem was the opposite of that used in the second period.

A record was kept of the time required to solve each problem, and of the number of errors made. Readings were taken of the pressure in pounds at 10-sec intervals. The subject was required to work until he obtained the correct answer unless his time exceeded three min, after which time was called. In the comparison of results, those problems not solved by a subject within three min in both attempts were discarded. However, if a subject failed to solve a problem on one attempt but did solve it on the other, the unsolved problem was given an arbitrary score of 190 sec.

Results

A comparison is made in Table I between the problems worked on the first occasion under normal conditions and the same problems worked on the first occasion under tension. The mean time for the tension condition is 75.7 ± 2.1 sec, and for the normal condition, it is 74.2 ± 2.0 sec. The difference between the two conditions is -1.5 ± 2.9, which is not a reliable difference.

Considering the same problems worked on the second occasion, the mean under tension is 50.8 ± 1.6 sec, and under normal conditions 54.8 ± 1.7 sec. The difference between the

two conditions is 4.0 ± 2.3 sec, which is also not a reliable difference. Our results do not show any reliable difference between the ability to solve problems under increased tension and under normal conditions.

TABLE I

THE INFLUENCE OF TENSION ON THE TIME (IN SECONDS) REQUIRED TO SOLVE ARITHMETICAL PROBLEMS

	First Occasion		Second Occasion	
	Tension	Normal	Tension	Normal
Mean	75.7±2.1	74.2±2.0	50.8±1.6	54.8±1.7
S.D.	58.4	56.4	45.0	49.1
N	367	367	367	367
Diff. (N–T)	−1.5±2.9		4.0±2.3	

TABLE II

THE INFLUENCE OF TENSION ON THE NUMBER OF ERRORS MADE IN ATTEMPTING TO SOLVE ARITHMETICAL PROBLEMS (COMBINED RESULTS OF THE FIRST AND SECOND OCCASIONS)

	Tension	Normal
Mean	23.6±1.7	27.7±2.2
S.D.	10.6	13.7
N	18	18
Diff. (N–T)	4.1±2.8	

The number of errors made under each of the two conditions is shown in Table II. The problems worked on both occasions were combined for this comparison. The mean number of errors per subject under tension is 23.6 ± 1.7, and the mean number of errors under normal conditions is 27.7 ± 2.2. The difference between the two conditions is 4.1 ± 2.8, and this difference is not reliable.

The correlation between the time required to solve the problems and the pressure registered at the time of solution is − .017 ± .022, which is based on 700 cases. There seems to be no relation between the amount of pressure at the time of solution and the speed of solving the problems. The distributions of all these time and pressure scores are given in Table III. It will be noted from this table that the average amounts of pressure for problems of different degrees of difficulty are practically the same.

TABLE III

THE RELATION BETWEEN THE TIME REQUIRED TO SOLVE ARITHMETICAL PROBLEMS AND PRESSURE AT THE TIME OF SOLUTION

	Pressure in Pounds																	
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	N	Av.
Time in Sec																		
170–179	1		2	3	3	2			1	2	2						16	30.0
160–169			2			4	3	1	1							1	12	31.0
150–159			4	1					2		1						8	29.7
140–149		1	1	2	1	2		1		1		1	1			1	12	31.4
130–139			2	3	1	2		1					1	1			11	30.3
120–129	1		3	2	1	6	2	1		1	1		1	1			20	30.4
110–119		2		3				1	4	3			1				14	31.3
100–109	2		1	2	2	2	1	3		1		1	3		1		19	31.4
90–99		1	2	2	1	2	3	1		1	1		2	1			17	31.2
80–89		1	7	4	3	5	4		1	1		3			2	1	32	30.6
70–79			2	2	8	4	1	4	3	1	2	2		1	2	1	33	31.9
60–69				8	8	5	1	1	2	4	1	1	2				33	30.8
50–59			7	11	5	6	5	4	5	2	3	1	2	2	1	1	55	31.0
40–49		1	4	10	8	9	11	5	4	13	5	1	1	1		1	74	31.3
30–39		1	12	13	8	9	6	6	4	6	6	6	3		2		82	31.0
20–29		1	11	16	16	11	6	9	7	5	6	4	4	3	6	5	110	31.7
10–19	1		3	18	18	17	7	7	13	5	6	7	1	1		2	106	31.1
0–9				4	10	11	3	4	2		2	3		3	1	3	46	31.9
N	5	8	63	104	93	97	53	49	49	46	36	30	22	14	15	16	700	
Av.	105.0	82.5	70.4	53.6	45.6	55.8	54.0	50.3	51.5	54.6	44.8	41.6	69.5	49.3	47.0	46.2		

TABLE IV

THE RELATION BETWEEN THE TIME REQUIRED TO SOLVE ARITHMETICAL PROBLEMS AND THE AVERAGE PRESSURE EXERTED DURING THE SOLUTION OF THE PROBLEMS (READINGS OF PRESSURE WERE TAKEN AT 10-SEC INTERVALS)

	Pressure in Pounds																	
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	N	Av.
Time in Sec																		
170–179			2	4	2	2	1	1	3	1							16	30.0
160–169		1	1		2	3	2	1	1	1							12	30.1
150–159		2	3			1	1	1									8	28.2
140–149		1		4	2			1		1	1	2					12	30.7
130–139			1	4	1	2			1			1	1				11	30.3
120–129				5	2	3		2	3	2		1	1				19	31.1
110–119			1	3	2	1		3	4			1					15	30.7
100–109	1	1	1	4	1		2	1	1	2	1	3					18	30.9
90–99			2	3	2	2	1		2	3	1	1		1			18	31.3
80–89		2	5	9	3	2			3	4	1	1			1	1	32	30.3
70–79			2	3	4	5	6	2	3	2	2	1		2	1		33	31.5
60–69			3	6	7	4	2	1	3	3	2	2					33	30.5
50–59			6	10	7	6	7	4	4	4	1	1	3	1	1		55	30.8
40–49		1	8	7	9	9	11	5	8	7	5	2	1		1		74	31.0
30–39		2	10	14	8	10	6	6	6	7	4	5	1	3			82	30.8
20–29		1	11	18	14	10	8	11	5	6	8	2	3	5	4	4	110	31.5
10–19	1		4	17	18	17	6	7	16	5	5	6	1	1		2	106	31.0
0–9				5	10	11	3	4	2		2	2		3	1	3	46	31.7
N	2	11	60	116	94	88	56	50	65	48	33	31	11	16	9	10	700	
Av.	60.0	94.0	61.1	58.4	49.2	50.0	52.5	52.2	58.3	60.8	42.8	59.1	54.0	35.0	40.5	23.0		

The correlation between the time required to solve the problems and the average amount of pressure registered while the subject was working on the problems is $-.200 \pm .024$. This correlation with time is much more significant than that found when pressure at the time of solution was used. The distributions of all of these time and pressure scores are given in Table IV. In this table, as in Table III, the average amounts of pressure for problems of different degrees of difficulty are practically the same.

Summary and Conclusions

The purpose of the present experiment was to compare the time required to solve short arithmetical problems under normal conditions and the time required to solve the same problems when the subject exerted a pressure between 25 and 40 pounds with his right foot on a pedal apparatus. Each subject solved each problem under the two conditions, half of them doing a problem first under tension and later under normal conditions and the other half doing the problem first under normal conditions and later under tension.

The correlation of $-.200 \pm .024$ between the time required to solve the problems and the average pressure exerted during the solution of the problems, as indicated by the results of Table IV, shows that there is some negative relation between these two factors. This does not mean, however, that there is a causal relation between the two factors. Several of the scores in the lower right-hand portion of Table IV were obtained from only two subjects who solved the problems in a short time and who also pressed relatively hard on the pedal. It seems probable also that some of the subjects became tired of maintaining the highest pressure for the long periods of time. The most general conclusion which seems justified by all of the results of our experiment is that increasing the tension of the right leg does not in itself definitely increase the efficiency of solving arithmetical problems.

The present experiment and the one carried out by Bills (1) differ both in the details of procedure and in the nature of the results. Problem solving was used as the mental work

in our experiment in an effort to compare the effect of tension on higher mental processes in contrast to the more routine tasks used by Bills. Bills' results are somewhat difficult to interpret because gripping hand dynamometers may have been distracting, and may have caused the subjects to pay closer attention to the required tasks. The strength of these factors of distraction and attention was not known in Bills' experiment. We attempted to decrease the factor of distraction. The pedal apparatus was used because the majority of persons drive automobiles and are therefore accustomed to a somewhat similar situation. The subjects were asked whether or not they drove a car, and it was hoped that a comparison could be made between drivers and non-drivers. However, only three of the 18 subjects did not drive, and this matter was not considered in the results.

The results of the present experiment do not seem to conflict in any way with those obtained by Jacobson (**9**). His findings suggest that some tension is necessary for all mental activity. The subjects in the present experiment were working under a condition of normal body tension at all times, and our results indicate that an arbitrary increase in tension, of the kind and amount used, does not increase mental efficiency. Our results do not indicate that a minimum amount of tension is not necessary for ordinary mental activities.

(Manuscript received June 21, 1933)

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SIMILARITY AND RETROACTION *

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Most of the published experimental work on this subject reveals that investigators have attempted to control the degree of similarity between the original and interpolated activity by varying the number of *identical elements* which the two activities have in common (**1**, **2**, **3**). While this is perhaps the most unambiguous manner of conceiving the difficult category of psychological 'similarity,' it is evident also that it is somewhat too artificial and restricted. It would be interesting to use as interpolated activity material which varies from the original in a 'qualitative' fashion. We may conceive of a list of tasks varying in this manner from the original, and have a number of competent judges rank the tasks in an order of diminishing similarity with reference to it. This having been accomplished, we might proceed to determine the amount of retroactive inhibition exerted by these various interpolated activities. Such a procedure for determining degree of similarity, however, has obvious shortcomings. Even if we obtained perfect agreement among the various judges in their rank orders, we should be in possession only of relative positions which tell nothing of the *amount* of disparity involved. And in a problem of this kind, amount is the prime consideration.

A step in the appropriate direction may perhaps be made if we use as criterion of similarity the degree of correlation between the original and the interpolated activity. As we shall see later, the correlation coefficient does not relieve us entirely of our difficulties; nevertheless it has certain evident advantages. Our independent variable, therefore, becomes the degree of similarity between the original and interpolated

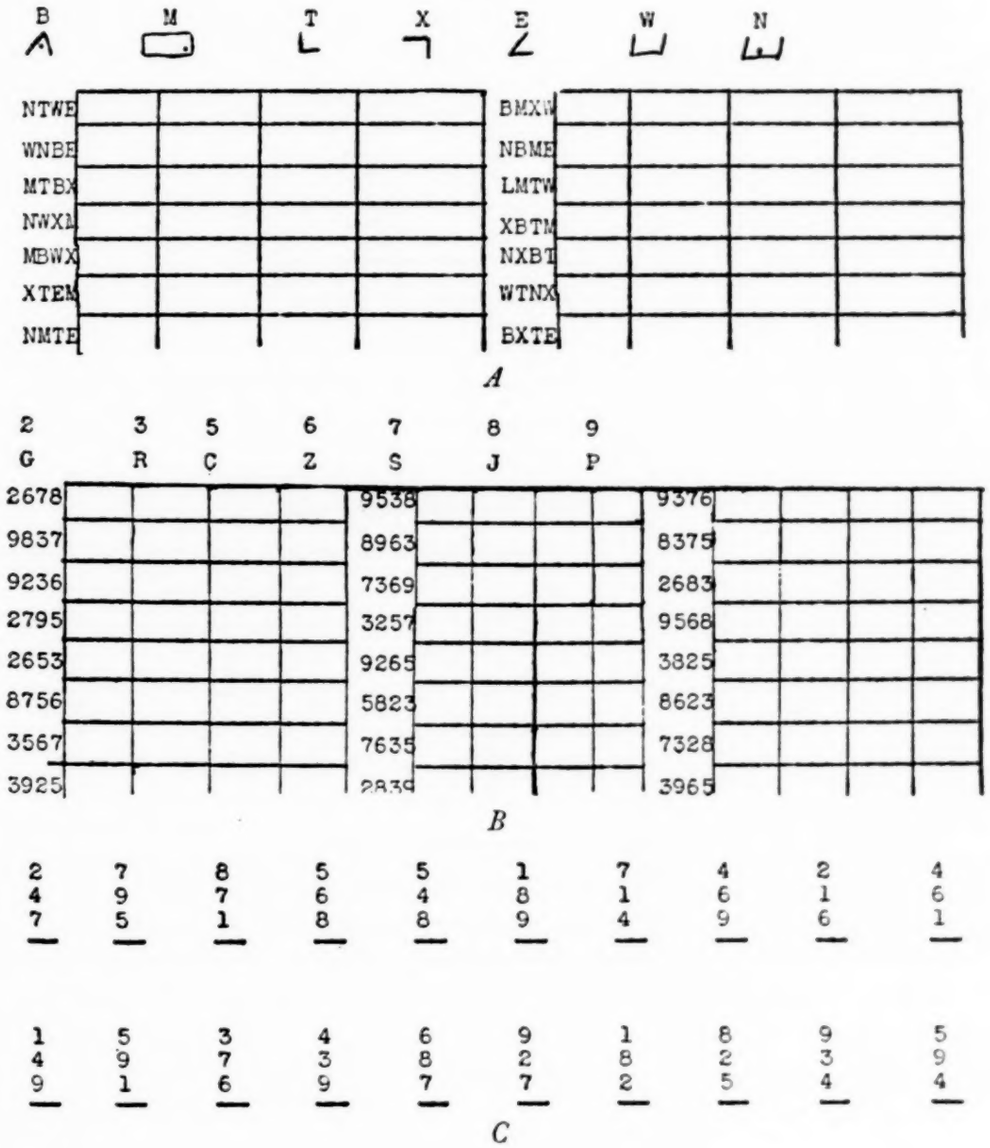
* Acknowledgments are herewith expressed to Miss Kathryn McCune for her invaluable aid in the scoring and tabulating of the material.

activity as expressed by the correlation coefficient obtaining between them; our dependent variable is the corresponding amount of retroactive inhibition effected. If our interpolated tasks are sufficiently diverse, we may hope to get degrees of similarity varying from unity to zero, and by expressing our obtained function in graphic form, to scrutinize it for any evidence of inversion (see **3**).

Method and Procedure

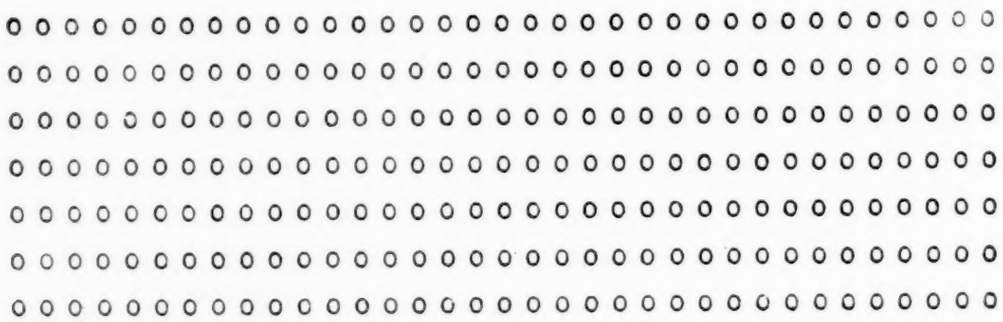
Guided by the preceding considerations, we constructed six different tasks to be used as interpolated material: *B*, *C*, *D*, *E*, *F* and *G*. Task *A* was used in all cases as the original activity. All the tasks were of the paper and pencil variety and are reproduced in Fig. 1. It will be noted that tasks *A*, *B*, *F* and *G* are code transcription tests,

Fig. 1

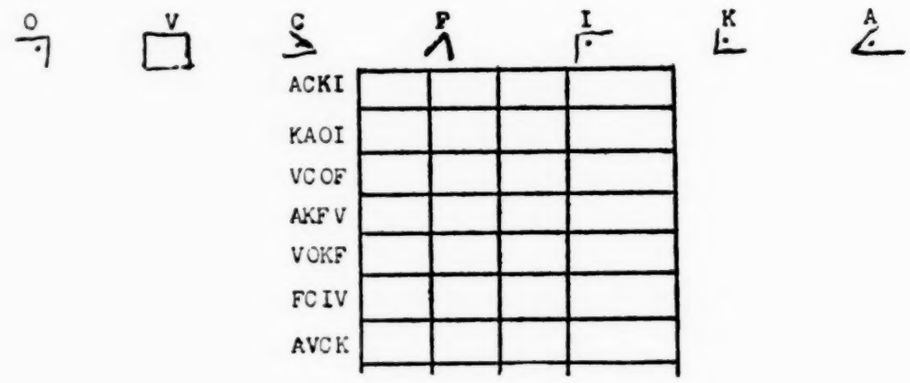


"In the beginning, when Twashtrai came to the creation of woman, he found that he had exhausted his materials in the making of man, and that no solid elements were left. In this dilemma, after profound meditation, he did as follows: He took the rotundity of the moon, and the curves of the creepers, and the clinging of tendrils, and the trembling of grass, and the slenderness of the reed, and the bloom of flowers, and the

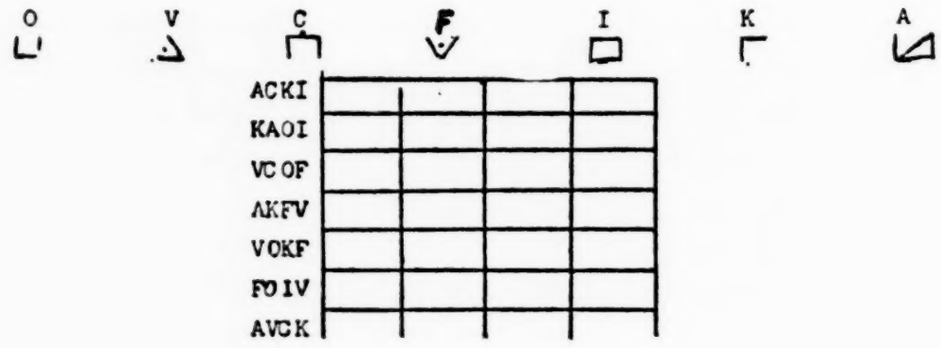
D



E



F



G

patterned after those used by Dreis.[1] Task *C* is composed of problems in addition; *D* is a letter-checking problem, in which each letter *e* is to be checked; in task *E*, the subjects were asked to put a dot in each circle at the beat of a metronome. (Metronome rate, 48 beats per minute.)

Eight groups of subjects were used. These individuals were college sophomores and juniors taking Psychology IA and IB. Males and females were represented in the ratio 1 : 3. The subjects did not know of the purpose of the experiment. The routine of tasks assigned to each group is shown in Table 1. Group 1 had as its interpolated activity, task *A* (identity); Group 8 had no interpolated task whatsoever, and serves as a control. The following routine of work and rest was observed for each group of subjects (with exception of Group 8, to be noted):

(*A*)		(Int)		(*A''*)
Original activity	Rest	Interpolated activity	Rest	Resumption of original activity
5′	1′	3′	1′	5′

For Group 8:

(*A*)		(*A''*)
Original activity	Rest	Resumption of original activity
5′	5′	5′

The experiment proper, therefore, required 15 minutes of the students' time.

The experiments were carried out in class on the entire group simultaneously. The tasks were on mimeographed sheets which had been stapled together with one blank sheet of paper between successive tasks (to prevent the subjects from seeing through to the sheet beneath) and were given out to the class face down.

The E read the following instructions:

"Do not turn the papers face up until I say Ready, Go. You will find on the first page a situation of this sort." (Here the E turned to the blackboard and reproduced the mimeographed sheet, using geometrical symbols and letters not contained in the students' copy. He then proceeded to give a demonstration of what was to be done. The same symbols and letters were used for each group.) "Does everyone understand? Any questions? Get set. Ready, Go."

"Stop. Turn over the page and fold it back. Leave the blank page where it is. When I say Ready, Go, turn over the blank page and begin working on the next page." (Here the E swiftly gave a demonstration of what was to be expected on the next page—the interpolated task. This usually required about 20 seconds. The remainder of the time was used by the E in speaking informally to the students and in exhorting them to keep their mind off the preceding task and to relax.) "Get set. Ready, Go."

"Stop. Turn over the page and fold it back. Leave the blank page where it is. When I say Ready, Go, turn over the blank page and begin working on the next page." (The intervening time was utilized by making casual remarks to the Group to keep their minds off the preceding activity. A few seconds before the Ready signal was given, the S's were told that the next task was a repetition of the first one.) "Get set. Ready, Go."

"Stop. Put your section number on the paper, the date, and pass it over to your right."

[1] *A* is identical with that used by Dreis, and thanks are here tendered for the loan of copies of her mimeographed blanks.

TABLE 1

S's Score = Number of correct items

	Group 1. $N = 77$			Group 2. $N = 65$			Group 3. $N = 76$			Group 4. $N = 77$			Group 5. $N = 79$			Group 6. $N = 80$			Group 7. $N = 45$			Group 8. $N = 80$	
	A	*A'*	*A''*	*A*	*B*	*A''*	*A*	*C*	*A''*	*A*	*D*	*A''*	*A*	*E*	*A''*	*A*	*F*	*A''*	*A*	*G*	*A''*	*A*	*A''*
Mean of absolute scores	117.62	85.35	156.74	118.0	97.04	158.1	111.34	87.11	146.4	114.26	146.58	151.77	118.3	144.0	156.11	121.0	71.86	150.52	111.62	65.77	139.68	109.25	145.18
σ of absolute scores	17.84	14.32	26.19	19.32	13.38	27.70	19.87	19.24	25.72	18.82	23.91	23.62	19.27	∞.	27.18	16.67	11.07	22.65	23.27	12.37	28.96	17.12	25.14
Mean % improvement	34.44			35.36			33.23			34.33			32.59			25.2			25.53			31.93	
σ % improvement	15.5			13.59			16.59			14.38			13.69			12.06			11.69			18.01	
"r" between original and interpolated material	.78			.64			.09			.41			.00			.73			.85			$r_{AA''} = .78$	
P.E.$_r$	±.03			±.05			±.08			±.06						±.04			±.03			±.03	

Results

Table 1 summarizes the results obtained. Figure 2 expresses the relationship between the two variables in graphic form. It will be noted (1) that the greatest amount of retro-

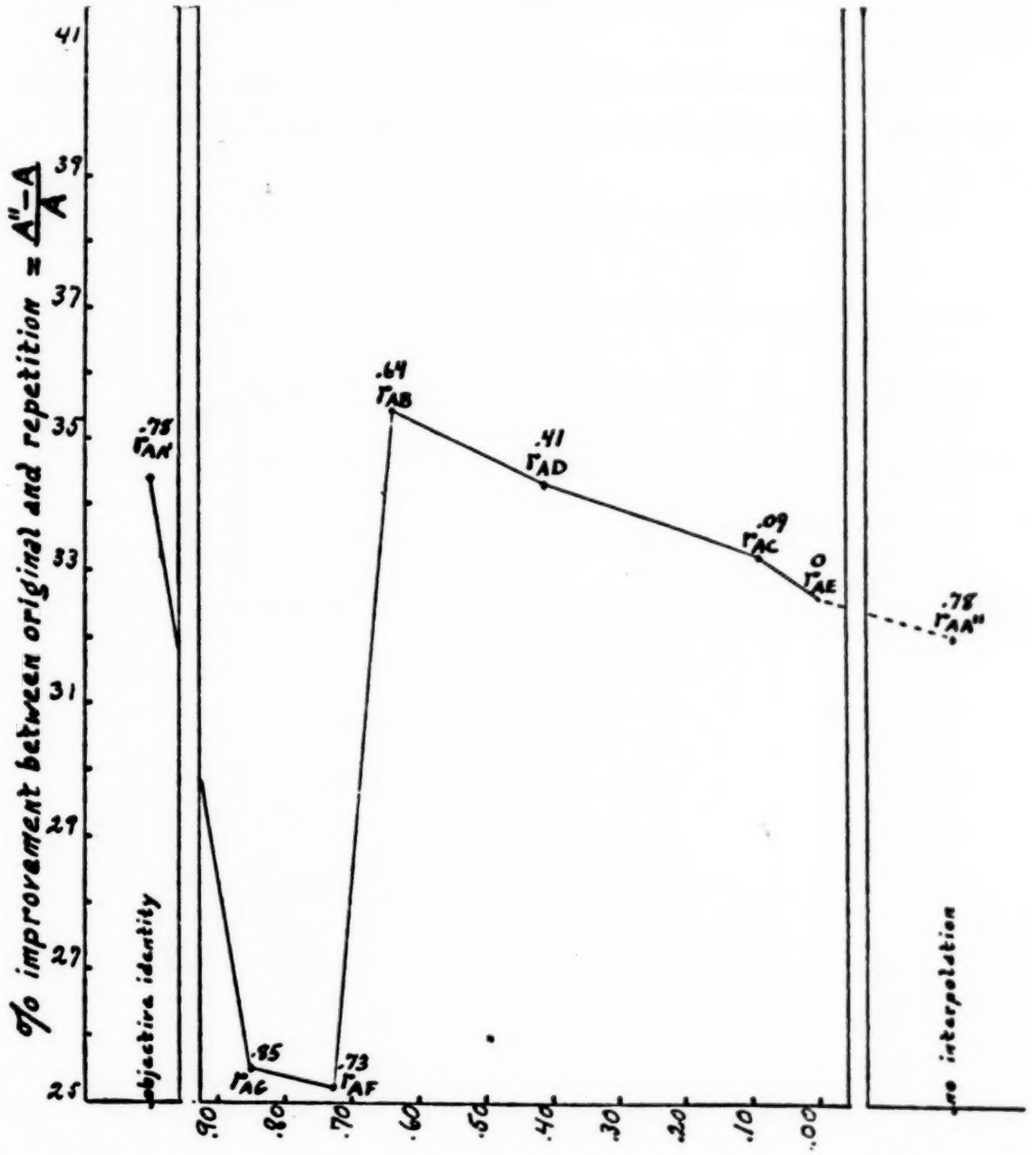


Fig. 2. Degree of similarity between original and interpolated activity (raw '*r*'s').

active inhibition is effected by the interpolated tasks *G* and *F*; (2) that the highest correlation between original and interpolated activity is furnished by Group 7 where the interpolated activity was task *G*, rather than by Group 1 where the interpolated and original activities are objectively identical. Thus $r_{AG} = .85$, while $r_{AA'} = .78$. Although the score for *A* is

based on 5 minutes work, whereas the score for *A'* is based on 3 minutes work, this discrepancy can hardly be held accountable for the latter correlation, since Group 8 gave likewise a correlation ($r_{AA'}$) of .78. The responsibility for the size of $r_{AA'}$ may therefore be attributed to the disrupting influence of practice effect.

The coefficient of reliability for the various tasks was not obtained, although Dreis reports that the reliability of task *A* is .81.

Inspection of Fig. 2 reveals that as we start from objective

TABLE 2

% Improvement in Series	% Improvement in Series	Difference	P.E.$_D$	$\frac{D}{\text{P.E.}_D}$	Chances in 100 that True Diff. > 0 and in Same Direc.
A-A'-A'' 134.44	*A-G-A'* 125.53	8.9	±1.7	5.2	99^+
A-A'-A'' 134.44	*A-F-A'* 125.2	9.2	±1.5	6.1	99^+
A-A'-A'' 134.44	*A-B-A'* 135.36	.9	±1.6	.6	66
A-A'-A'' 134.44	*A-D-A'* 134.33	.1	±1.6	.1	53
A-A'-A'' 134.44	*A-C-A'* 133.23	.2	±1.8	.1	53
A-A'-A'' 134.44	*A-E-A'* 132.59	1.9	±1.6	1.2	79
A-A'-A'' 134.44	*A-A'* 131.93	2.5	±1.8	1.4	83
A-B-A' 135.36	*A-F-A'* 125.2	10.1	±1.5	6.7	99^+
A-B-A' 135.36	*A-G-A'* 125.53	9.8	±1.6	6.1	99^+
A-B-A' 135.36	*A-D-A'* 134.33	1.	±1.6	.6	66
A-B-A' 135.36	*A-C-A'* 133.23	2.1	±1.7	1.2	79
A-B-A' 135.36	*A-E-A'* 132.59	2.8	±1.5	1.9	90
A-B-A' 135.36	*A-A'* 131.93	3.4	±1.8	1.9	90
A-D-A' 134.33	*A-C-A'* 133.23	1.1	±1.7	.6	66
A-D-A' 134.33	*A-E-A'* 132.59	1.7	±1.5	1.1	77
A-D-A' 134.33	*A-A'* 131.93	2.4	±1.8	1.3	81
A-C-A' 133.23	*A-E-A'* 132.59	.6	±1.7	.4	61
A-C-A' 133.23	*A-A'* 131.93	1.3	±1.9	.7	68

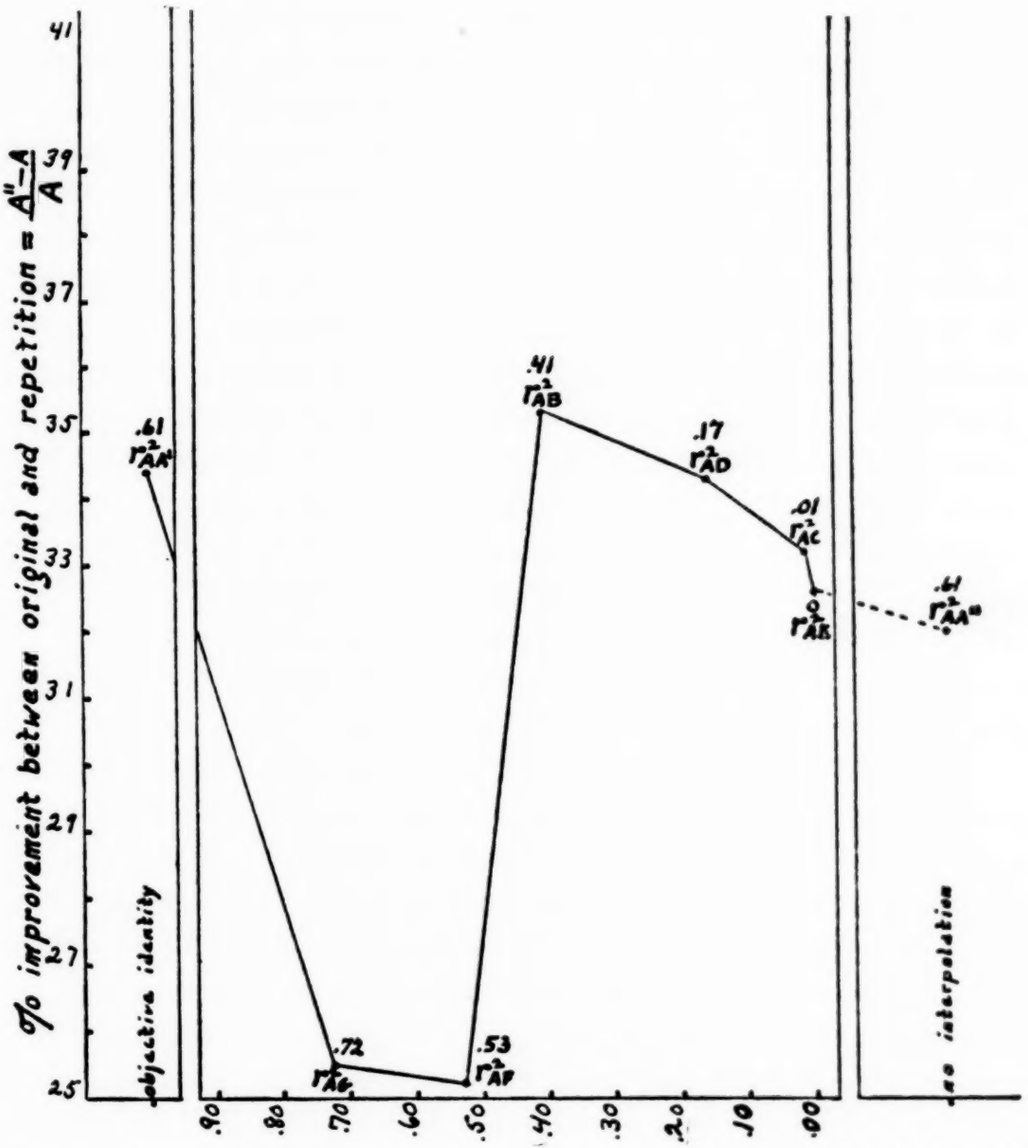


FIG. 3. Degree of similarity between original and interpolated activity (raw '*r*'s' squared).

TABLE 3

		Difference	P.E.$_D$	$\frac{D}{\text{P.E.}_D}$	Chances in 100 True Diff. > 0 and in Same Direc.
$r_{AA'} = .78$	$r_{AB} = .64$	.14	±.06	2.3	94
$r_{AA'} = .78$	$r_{AD} = .41$	.37	±.07	5.3	99^+
$r_{AA'} = .78$	$r_{AF} = .73$	.05	±.05	1.	75
$r_{AA'} = .78$	$r_{AG} = .85$	.07	±.04	1.7	87
$r_{AG} = .85$	$r_{AB} = .64$	.21	±.06	3.5	99
$r_{AG} = .85$	$r_{AD} = .41$	.44	±.07	6.3	99^+
$r_{AG} = .85$	$r_{AF} = .73$	.12	±.05	2.4	95
$r_{AF} = .73$	$r_{AB} = .64$	.09	±.06	1.5	84
$r_{AF} = .73$	$r_{AD} = .41$	.32	±.07	4.6	99^+
$r_{AB} = .64$	$r_{AD} = .41$	.23	±.08	2.9	97

identity of the originaland interpo lated activity and proceed toward diminishing similarity, the amount of retroactive inhibition increases sharply until the abscissa value of .85 is reached, and it attains its maximum between .85 and .73. Beyond this latter point, we obtain an inversion and the retroactive effect diminishes just as sharply, reaching its minimum value at .64. From here, the curve drops in a linear manner. In fact, it would appear from this linear segment of the curve that the interpolated tasks *B*, *D*, *C* and *E* give rise to a slight positive transfer effect, and it is interesting and suggestive to note that the amount of this effect seems to vary directly with the degree of correlation (similarity) between the original and interpolated tasks. We did not, in our experiments, take measures to eliminate this positive transfer effect, which resulted probably from the acquisition by the S's of certain general sets and techniques of procedure, supplied by the performance of the interpolated task.

Since the 'raw' correlation between two variables is known not to give the degree of commonality between them except under a limiting condition, it was decided to square the *r*'s obtained and plot the curve on the basis of these squares (Fig. 3). As is well known, the mere squaring of the obtained *r*'s likewise does not guarantee the securing of the true degree of commonality between two variables except in certain very limiting conditions (4), and we may be reasonably certain that our present data do not conform to these conditions. We have, nevertheless, proceeded on the assumption that this presents a more, if not entirely, accurate picture of the situation. (See 4, p. 432.)

Summary

1. In the present study as the degree of similarity between the original and interpolated activity (as measured by *r*'s uncorrected for attenuation) decreases from identity, the amount of retroactive inhibition increases sharply until it reaches a limit at $r = .73$. Here we have an inflection in the curve and it rises sharply until a limit is reached at $r = .64$, this being the point of minimum retroactive inhibition or

maximum improvement. As the similarity diminishes further, the amount of improvement in the relearning of the original activity diminishes steadily until the point of zero similarity is reached.

2. Interpolated tasks, bearing a resemblance to the original not greater than .73, effect a certain amount of positive transfer which varies directly as the degree of resemblance between the original and interpolated task.

3. In the present experiments, the presence of positive transfer served to mask and overcompensate the effect of any retroactive inhibition which may have existed in the range indicated in the preceding paragraph.

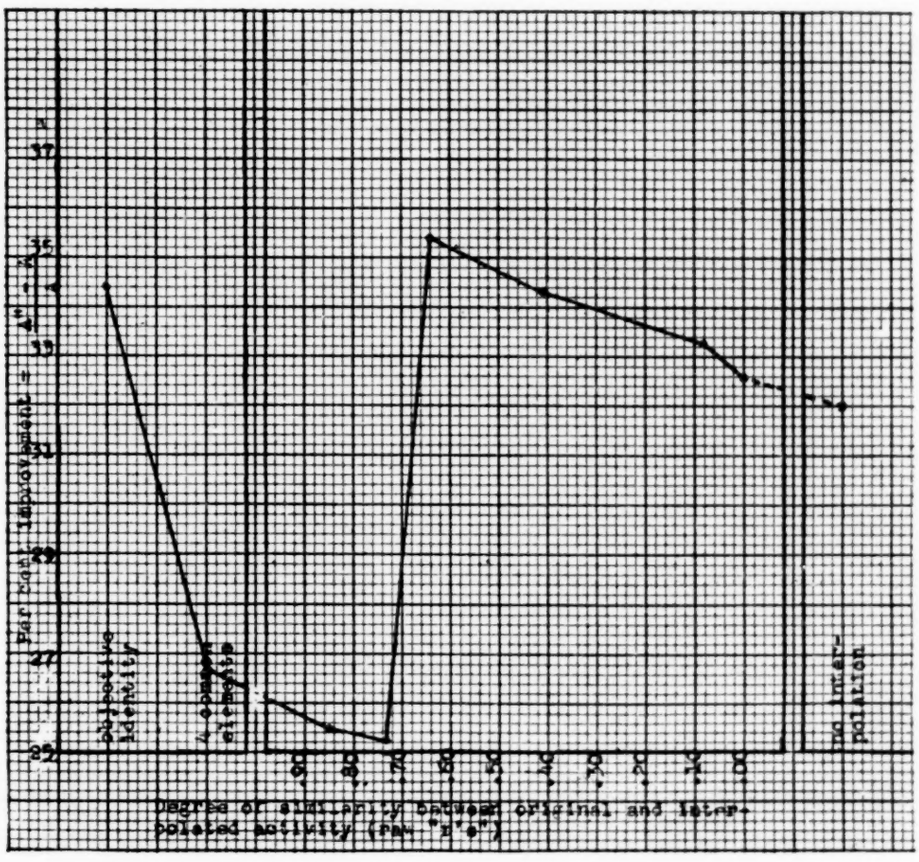


FIG. 4.

ADDENDUM

While the paper was in press, we were able to gather some additional data, wherein the interpolated task was in the na-

ture of a code transcription similar to tasks *F* and *G* but containing 4 elements which are objectively identical with those in Task *A*. A new group of 80 subjects was used. The mean per cent improvement for this new group was found to be 26.74. We take this occasion to incorporate this result in our findings (see Fig. 4).

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WHOLE AND PART METHODS IN TRIAL AND ERROR LEARNING

Human Maze Learning

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Introduction

Of the problems in the psychology of learning which have been studied in recent years few, if any, have led to such diversity of conclusions as investigations which have to do with the relative effectiveness of various procedures in learning. The whole method, modifications of the whole method, numerous part methods, and modified part methods have all been tested. There is as yet, however, no agreement among investigators as to whether a whole or a part method is to be preferred for any given type of learning material, nor even as to what are the advantages and disadvantages to be found in any method. To advocates of the whole procedure, that procedure is 'the only one which is psychologically justifiable,' 'by far the most economical,' 'requires fewer repetitions,' 'usually less time,' 'secures a more accurate reproduction and a more lasting retention.' Those who prefer a part procedure are no less enthusiastic in their claims and no less vigorous in their defense of their favorite procedures, and advocates of the two general methods are about equally divided in number.

In an earlier paper a brief summary of the results of investigations of this subject was given and a new study of whole and part methods in trial and error learning was reported.[1] The learning material used in that study was mazes, each of which could be learned as a whole maze, or as four separate smaller mazes, or as mazes of intermediate size made

[1] Hanawalt, E. M., Whole and Part Methods in Trial and Error Learning, *Compar. Psychol. Monog.*, 1931, 7, No. 5.

up of two or three of the four parts. Each of these mazes and parts was different from any of the others in design and was difficult enough to test adequately the learning methods employed. The subjects used were white rats which had been thoroughly trained in maze learning. The whole procedure was compared in turn with each of the following part procedures:

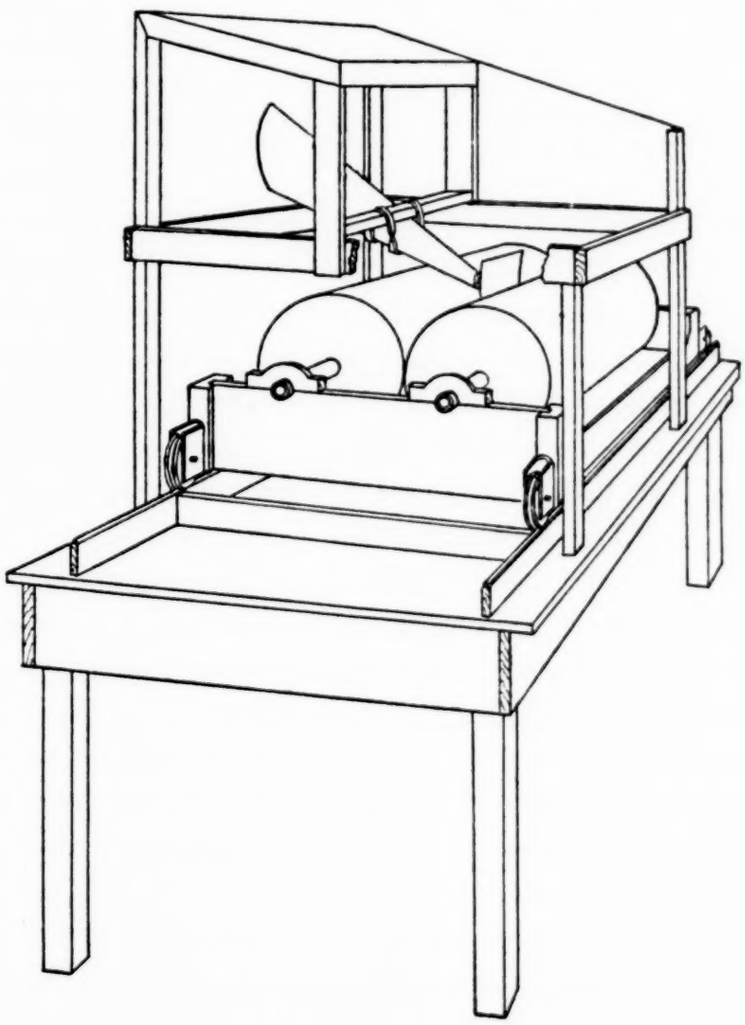
Pure part (part I, then II, then III, then IV, then I–II–III–IV)
Progressive part (part I, then II, then I–II, then III, then I–II–III, then IV, then I–II–III–IV)
Direct repetitive part (part I, then I–II, then I–II–III, then I–II–III–IV)
Reversed repetitive part (part IV, then III–IV, then II–III–IV, then I–II–III–IV)

In each maze, large or small, three consecutive trials without error were required as evidence of mastery. In that study, when measured in terms of units of total distance required for mastery, the order of effectiveness of methods tested, from greatest to least, proved to be whole, direct repetitive part, pure part, progressive part, reversed repetitive part.

The investigation presented in this paper is a repetition of that study, using human instead of animal subjects. The subjects, 8 in number, were drawn from the advanced classes and from the staff of the Department of Psychology at the University of Michigan. Each subject was thoroughly trained and experienced in maze learning before beginning work in this experiment. The learning material used, the general procedure employed, and the items compared were the same in the animal and human studies, but the apparatus was different. As in the previous experiments, the item considered of most value in determining the relative effectiveness of the procedures tested was the number of units of total distance taken. This item represents more truly than any other the amount of energy expended in learning. It was computed by the formula: number of trials $\times$ length of true pathway $+$ number of units of excess distance taken.

Description of Apparatus

The apparatus employed was that designed by Prof. J. F. Shepard and used in the psychological laboratories at the University of Michigan (Fig. 1). It included two sheet metal cylindrical drums, one 36″ in length and 12″ in diameter, the other 54″ in length and 10″ in diameter, placed together horizontally parallel on the same level. Both drums had rods extending from the centers at both ends forming axes



which fitted into bearings in an oblong framework. The drums were belted to each other in such a way that, whenever the observer placed his hand upon one and rotated it toward or away from himself, the other automatically rotated in the same direction. The framework carrying the two drums was mounted upon small wheels much after the fashion of a car. The rims of the wheels were grooved and set upon rails 10′ in length. These rails fitted nicely into the grooves. The observer, standing in front of the drums, by placing his hands upon the one nearer him and pushing gently to the right or left, could move the entire framework in either direction. Thus it was possible for an individual to control the movement of either drum, causing it to rotate either forward or backward or to slide to the right or to the left.

The maze pattern was in the form of a blue line print mounted upon the surface of the bigger drum farther removed from the observer. The subject, with the palms

of his hands resting upon the nearer drum, stood or sat (as he chose) looking through a metal cone which was suspended from a second and higher framework and directed toward the blue line printed maze pattern mounted upon the farther drum. The cone was graduated in diameter and the aperture near the blue print was of such size that the subject could see only one square unit of pathway at a time. The subject looked into the larger end of the cone. A curtain surrounding the cone at the observing end screened the subject from the farther drum and prevented him from seeing the design of the maze as a whole.

The problem of the subject, then, as he looked through the cone, was to practice moving the units of pathway in each maze before him backward, forward, to the right and to the left, as the pattern required, until he was able to travel in this manner from beginning to end three consecutive times without making a false move.

Comparison of Whole Procedure with Pure Part Procedure

One pair of mazes and 7 subjects were employed to compare the relative effectiveness of the whole and pure part procedures in learning. The first maze, PW VI, contained 351 units of true pathway and 147 units of false pathway; the second, PW VII, contained 355 units of true pathway and 155 units of false pathway. In learning Maze PW VI, 3 subjects constituted the 'whole' group and 4 constituted the 'part' group. In learning Maze PW VII the groups were reversed. Members of the whole group were required to traverse the entire maze from beginning to end in each trial. Members of the part group learned each quarter of the maze separately and then the four parts combined (or the whole). Three consecutive correct trials were taken as the standard for mastery.

The learning of each maze as a whole and the learning of each part into which the mazes were divided for the part group, proceeded in the way usual for trained subjects. Errors and hesitations occurring in the early trials were gradually eliminated and finally the required standard of accuracy was attained. When the subjects of the part group were transferred from part IV to the whole maze there was, strangely enough, no recognition by any subject of the fact that the large maze being learned was composed of the smaller units already mastered. Each subject learned it in the same way that he learned any new maze. Averages taken for all subjects on both mazes showed that mastery of the maze as a

whole after the parts had been learned separately required more effort than was required to learn all the parts singly, whether measured in terms of number of trials required, amount of time spent, number of errors made, number of units of excess distance taken, or total distance traversed. This was not true, however, for every subject in every item, but it was true for all subjects in some items and for most subjects in most items. It is apparent that approximately 2/3 of the energy of the learners was spent upon the task of combining into a whole the parts which had already been learned singly, a result identical with that obtained in animal learning when the pure part procedure was employed. Notwithstanding the fact that more energy was expended in combining the parts than was expended in learning them separately, it is clear that some learning was retained from having first mastered the parts singly, for the average amount in trials, time, errors, excess distance, and total distance was less for members of the part group in traversing the whole maze than for members of the whole group when both mazes are taken together, and this, too, was found to be the case in the animal study. However, this was not true of Maze PW VI in the human study when taken alone, though the total energy expended by the part group was considerably more than twice that expended by the whole group even on that maze. Averages for all subjects learning by the part method on both mazes taken together show that the energy expended

TABLE I

	Part I	Part II	Part III	Part IV	Parts Singly	Parts Combined into Whole
Trials	9.0%	9.6%	8.9%	9.8%	37.3%	62.7%
Time	7.7	9.9	9.8	9.5	36.9	63.1
Errors	4.9	7.3	6.2	6.6	25.0	75.0
Excess distance	5.1	7.5	6.4	5.8	24.8	75.2
Total distance	8.0	9.5	8.2	9.8	35.5	64.5

on the various learning acts was distributed as in Table I. When averages were taken for all subjects of both groups on both mazes, the whole method of learning proved to be decidedly superior to the part procedure in this test. In one

item (number of units of excess distance taken) the part procedure had a very small advantage (1.8 percent) and in another item (number of errors made) the advantage of the whole was so slight as to be negligible (.3 percent), but in the other items the advantage of the whole procedure was large—24.0 percent in number of trials, 20.6 percent in amount of time, and 28.1 percent in number of units of total distance traversed—and this was true for each individual subject as well as for the group taken together.

Summarizing the results obtained in this test of the relative effectiveness of the whole and the pure part procedures, we find

1. That the whole procedure proved to be superior in respect to number of trials, amount of time, and number of units of total distance required for learning, but there was a slight advantage in favor of the pure part procedure in respect to number of units of excess distance taken. In respect to number of units of total distance taken, which is the truest measure of energy expended, the advantage of the whole procedure was 28.1 percent.

2. That in the pure part procedure, learning the parts constituted approximately 1/3 and learning to combine the parts into the whole approximately 2/3 of the learning activity.

3. That, when all criteria are taken together, learning the parts singly first did appear to reduce somewhat the amount of energy required to master the whole later, though there are exceptions in different items for individuals.

4. That parts learned singly did not function perfectly when combined to form the whole, but in the new combination required more practice for mastery than had been necessary for original learning.

Comparison of Whole Procedure with Direct Repetitive Part Procedure

One pair of mazes and 8 subjects were employed in comparing the relative effectiveness of the whole and the direct repetitive part procedures in learning. The first maze, PW X, contained 369 units of true pathway and 152 units of false

pathway; the other, PW XI, contained 376 units of true pathway and 154 units of false pathway. The subjects were divided into two groups, each of which learned one maze by the whole method and the other by the direct repetitive part method. Subjects of the whole group were required to traverse the maze from beginning to end in each trial. Those of the part group learned first Part I, then I and II together, then I–II–III in combination, and finally the whole maze, Parts I–II–III–IV combined, until the required standard of accuracy was attained in each case.

In this procedure the first portion of each new combination to be learned included what had already been learned, a fact which was recognized by all subjects excepting one before learning was completed. This recognition, however, in several cases seemed to the subject confusing rather than helpful in the mastery of the new combination, though in general it tended to reduce the amount of energy required for learning. Averages taken for all subjects on both mazes showed that mastery of the maze as a whole after the first three parts had been learned in successive cumulative series required considerably less effort than had been required to combine parts already learned singly in the pure part procedure. This was true with respect to every criterion employed though there were exceptions for some subjects in a few items. From the results obtained it is apparent that a little more than 2/3 of the energy was spent in mastering the first three parts in this procedure, and a little less than 1/3 was spent on the final learning act, or the mastery of the whole. In comparison with the animals which learned these mazes by this method, the human subjects spent a somewhat larger proportion of the total energy expenditure upon the part combinations and somewhat less on the whole. The actual percentages for the human subjects are found in Table II.

When averages were taken for all subjects of both groups on both mazes, the whole method of learning proved to be superior to the direct repetitive part method in this test. In one item, number of errors made, the part procedure showed a considerable advantage (14.3 percent); in another,

TABLE II

	Part I	I–II	I–II–III	Part Combinations	Whole
Trials	10.7%	23.4%	36.0%	70.1%	29.9%
Time	10.3	22.5	33.4	66.2	33.8
Errors	11.8	22.3	28.3	62.4	37.6
Excess distance	10.7	18.8	24.9	54.4	45.6
Total distance	10.9	24.4	34.1	69.4	30.6

units of excess distance taken, the advantage for the whole procedure was small (3.2 percent); but in the other items the advantage for the whole procedure was large—59.7 percent in number of trials, 55.5 percent in amount of time, and 55.7 percent in number of units of total distance taken. These items showed advantage for the whole method for individual subjects as well as for the group taken together.

Summarizing the relative effectiveness of the whole as compared with the direct repetitive part procedure as found in this study, we find

1. That the whole procedure was superior in respect to number of trials, amount of time, number of units of excess distance, and number of units of total distance required for learning; but there was an advantage in favor of the direct repetitive part procedure in respect to number of errors made. In number of units of total distance taken, which is the most important criterion, the advantage for the whole procedure was 55.7.

2. That in the direct repetitive part procedure, learning 3 of the 4 parts constituted somewhat more than 2/3 of the learning activity, and completing the learning by the addition of the fourth part somewhat less than 1/3 of the total learning activity.

3. That learning Parts I–II–III in combination by the direct repetitive part procedure reduced considerably the amount of energy required to master the whole after Part IV had been added.

4. That parts learned in succession and cumulatively combined did not function perfectly when put into combination to form the whole, but in that new combination required practice for mastery.

Comparison of Whole Procedure with Reversed Repetitive Part Procedure

One pair of mazes and 8 subjects were employed in comparing the relative effectiveness of the whole and the reversed repetitive part procedures in learning. The first maze of the pair, PW IV, contained 394 units of true pathway and 152 units of false pathway; the second, PW V, contained 413 units of true pathway and 157 units of false pathway. The subjects were divided into two groups, each of which learned one maze by the whole and one by the part method. Subjects of the whole group were required to traverse the maze from beginning to end in each trial. Those of the part group learned first Part IV, then Parts III–IV together, then Parts II–III–IV in combination, and finally the whole maze, Parts I–II–III–IV combined, until the required standard of learning was attained in each case.

In this procedure the first portion of each new combination to be learned was made up of that which was new and the latter portion of that which had already been learned. None of the four subjects who learned PW IV by this part procedure recognized any of the paths in the successive combinations as previously learned. Among the subjects who learned PW V by the part procedure there was some indication of recognition after the first three combinations (IV, III–IV, II–III–IV) had been mastered and the maze was being traversed as a whole, but this recognition did not appear to facilitate final mastery. One subject, who took three trials to master the final combination, asked after learning had been completed, if certain paths (those constituting Part III) were not the same as in the previous maze. Another subject, after his second trial on the final combination, made the statement "the maze is the same as the previous one only a little has been added at the beginning," but he had already taken 14 trials to master the II–III–IV combination and then, even though he recognized the relationship, took 8 trials to learn the final combination. A third subject was apparently vaguely aware of resemblance in the last two combinations, for he remarked after his third trial on the final combination, "The last two or three paths

of this maze look something like the end of the other one. That doesn't bother me any, though; neither does it help me." He required 24 and 11 trials respectively for the mastery of the last two combinations. Although no subject complained that such recognition confused him (a complaint actually made in learning by the direct repetitive part procedure), it is obvious, as indicated by the amount of energy required, that recognition did not aid in final mastery of the whole maze. The proportion of energy expended upon learning the combination forming the whole after the preceding part combinations had been mastered was even greater in Maze PW V, in which recognition occurred before learning was complete, than in Maze PW IV, in which there was no recognition of the relation between any of the successive learning acts during the entire learning process. When both mazes are taken together for all subjects learning by this part procedure, the results show that a little more than two-thirds of the energy was spent in mastering the three part combinations and a little less than one-third was spent on the final act of mastering the whole. These results differ very little from those obtained for animals learning the same mazes by the same procedures. The actual percentages for human subjects are given in Table III.

TABLE III

	Part IV	Parts III–IV	Parts II–III–IV	Part Combinations	Whole
Trials	6.3%	24.7%	39.3%	70.3%	29.7%
Time	6.2	25.7	36.7	68.6	31.4
Errors	4.0	27.7	27.7	59.4	40.6
Excess distance	4.4	28.3	28.8	61.5	39.5
Total distance	7.3	24.7	37.4	69.4	30.6

When averages were computed for all subjects of both groups on both mazes, the whole method of learning proved to be superior to the reversed repetitive part procedure in this test. This was true in all items and the percent of advantage for the whole procedure was large for each item—59.4 percent in number of trials, 49.8 percent in amount of time, 40.3 percent in number of errors, 45.4 percent in amount of excess distance taken, and 57.5 percent in total distance taken.

Summarizing the relative effectiveness of the whole and the reversed repetitive part procedures as tested in this study we find

1. That the whole procedure was distinctly superior in all respects. In respect to the number of units of total distance taken, which is the most important criterion employed, the advantage for the whole procedure was 57.5 percent.

2. That in the reversed repetitive part procedure learning the last three of the four sections of the maze constituted a little more than two-thirds of the learning activity and completing the learning by the addition of the first section a little less than one-third of the learning activity.

3. That learning Parts II–III–IV in combination by the reversed repetitive part procedure reduced somewhat the amount of energy required to master the whole after Part I was added.

4. That parts learned in reversed cumulative series did not function perfectly when combined to form the whole, but in the new combination required practice for mastery.

5. That in nearly all items for each maze and in all items for both mazes taken together, the amount of energy expended by the part groups of subjects on learning three of the four parts of a maze exceeded that expended by the whole groups on learning the maze as a whole.

6. That the advantage in favor of the whole procedure was greater when the whole procedure was compared with the reversed repetitive part procedure than when it was compared with either the pure part or the direct repetitive part procedure.

Comparison of Whole Procedure with Progressive Part Procedure

One pair of mazes and 8 subjects were employed in testing the relative effectiveness of the whole and the progressive part procedures in learning. The first maze of the pair, PW VIII, contained 404 units of true pathway and 152 units of false pathway; the second, PW IX, contained 395 units of true pathway and 150 units of false pathway. The subjects were

divided into two groups, each of which learned one maze by the whole method and one by the progressive part method. Subjects of the whole group were required to traverse the entire maze from beginning to end in each trial. Those of the part group learned first Part I, then Part II, then I and II together, then III, then I–II–III combined, then IV, and then I–II–III–IV together as a whole, until the required standard for mastery was attained. For subjects in the part group there were therefore seven separate learning acts.

This procedure is like the pure part procedure in that each of the four sections of the maze was learned separately; but it is unlike the pure part procedure in that, after being learned, each section in turn was made to function at once in a larger combination of parts. The separately learned parts were progressively added to each other until finally the whole was formed. Like the repetitive part methods, this learning problem grew progressively more complex; but unlike them, new and old parts were never combined in the same learning act. Moreover, learning was always in a forward direction.

Of the four subjects who learned PW VIII by the progressive part procedure, none recognized while learning that any portions of the larger combinations were previously learned material. One subject in the first trial on the final combination (Parts I–II–III–IV, or the whole) suggested that there seemed to be some similarity, but he required 12 trials to master that combination and remarked at the end, "I think the fact that in the first run I felt so sure I recognized the junctions as those of a previous maze interfered with learning." Another subject in the first trial of the Parts I–II–III combination remarked, "Haven't we had this one before? I guess not, but there are some places that look alike," and after his three final errorless trials on the whole maze said, "There are several pretty shaky places in this maze yet." All of the subjects who learned PW IX by the progressive part procedure did recognize before learning was completed that there was a relationship between the combinations being learned, but none of them found this recognition much aid in learning, as is indicated by the number of trials taken even

after recognition, and also by remarks of the subjects, such as, "When I get a whole maze together I get a pattern, all the turns in relation to each other, and it seems easier. When I get it in pieces I just learn piece by piece and find it hard to put the pieces together," and "The trouble is it doesn't do me any good to have caught on to the fact that this maze is made up of the parts I have already learned." As a matter of fact, however, those subjects who had recognized the relationship before reaching the final combination did require fewer trials to master the last combination than those who had not recognized that relationship. One subject, at this juncture, made a study of the corresponding animal experiment and thenceforth understood the nature of the problem. He believed that this understanding facilitated learning for him though actually the results proved even in his case to favor the whole procedure.

When both mazes are taken together for all subjects learning by the progressive part procedure, the results show that a little more than three-fourths of the total energy required for learning was spent in mastering the part combinations and a little less than one-fourth was spent on the final learning act, the mastery of the whole after all the parts had been learned and related. This distribution of energy expenditure was different from that found with the animals, which spent approximately two-thirds on the part combinations and approximately one-third on the final whole combination. The percentages for the human subjects are found in Table IV.

TABLE IV

	Part I	Part II	Parts I–II	Part III	Parts I–II–III	Part IV	Part Combinations	Whole
Trials	6.9%	7.3%	16.7%	7.1%	33.5%	7.7%	79.2%	20.8%
Time	7.6	6.9	17.7	6.8	29.8	8.6	77.4	22.6
Errors	7.2	9.2	15.2	7.6	27.0	7.9	74.1	25.9
Excess dist.	7.4	9.2	16.3	8.3	25.2	9.4	75.8	24.2
Total dist.	6.8	7.5	16.9	6.9	32.4	7.9	78.4	21.6

When averages were computed for all subjects of both groups on both mazes, the whole method of learning proved to be superior to the progressive part procedure in this test.

This was true in respect to all criteria and the percentage of advantage for the whole was very large—65.9 percent in number of trials, 59.6 percent in number of errors, 64.8 percent in amount of time, 57.3 percent in number of units of excess distance, and 64.7 percent in number of units of total distance traversed. This was a much larger advantage for the whole procedure than was obtained in the corresponding test with animals.

Summarizing the relative effectiveness of the whole and progressive part procedures as found in this study we find

1. That the whole procedure was distinctly superior in all items. In respect to the number of units of total distance taken, which is the most important measure, the advantage for the whole procedure was 64.7 percent.

2. That learning the parts and combining them, exclusive of the final combination which made the maze a whole, constituted a little more than three-fourths of the total learning activity, and completing the learning by mastery of the final whole combination a little less than one-fourth of the total learning activity.

3. That learning and relating the parts in progressive cumulative series first reduced the amount of energy required later to master the maze as a whole, and this reduction was greater when the subject was aware of the learning procedure being employed.

4. That parts learned singly and smaller combinations of parts already learned did not function perfectly when put together to form larger combinations or to form the whole, but required practice for mastery in their new relationship.

5. That in all items for each maze and for both mazes taken together the amount of energy expended by the subjects of the part group in learning and relating the parts, exclusive of the final combination into the whole, exceeded very greatly the amount of energy expended by the whole group in learning the maze as a whole.

6. That the advantage in favor of the whole procedure was greater when the whole procedure was compared with the progressive part procedure than when it was compared with

either the pure part, the direct repetitive part or the reversed repetitive part procedure.

Conclusions

From the results obtained [2] in the experiments described above we conclude that, for human subjects learning maze patterns, the whole method is superior to either the pure part method, the direct repetitive part method, the reversed repetitive part method, or the progressive part method.

In two of the tests (the reversed repetitive part and the progressive part procedures) the whole method proved to be superior in respect to all criteria employed; in the other two tests there was an exception of one item for each—an advantage of 1.8 percent for the pure part procedure in the number of units of excess distance taken and an advantage of 14.3 percent for the direct repetitive part procedure in the number of errors made. In respect to the number of units of total distance taken, which is the truest measure of energy expended, there was an advantage for the whole procedure in every test. Even if, in the cases of subjects learning by the part procedures, we leave out of consideration entirely the last three correct trials which are required as evidence of mastery of each part and part combination, still we find the advantage in total distance taken to be in favor of the whole procedure. We do not, however, believe it proper to exclude those trials since they are an inherent part of the procedures tested, but it does strengthen our argument in favor of the superiority of the whole procedure to indicate that the advantage is there whether those trials are included or not. The following Table V shows, both in absolute amounts and in percentages, the average amount of advantage in total distance taken for the whole procedure in comparison with each of the four part procedures tested.

Of the methods tested, the order of effectiveness from greatest to least was whole, pure part, direct repetitive part, reversed repetitive part, and progressive part. Whenever in

[2] Original data is on file in the offices of the Psychology Laboratories at the University of Michigan.

TABLE V

Part Method Employed	Subjects of Whole Groups Av. Total Distance Taken (y)	Subjects of Part Groups			Percent of Advantage for Whole Method $\left(\frac{x}{y}\right)$
		Av. Dist. Taken on Parts	Av. Dist. Taken on Whole	Av. Total Distance Taken (x)	
(Last Three Correct Runs on Part Combinations Included)					
Pure part	3549.0	1809.7	3128.9	4938.6	28.1%
Direct repetitive part	1667.5	2610.4	1158.1	3768.5	55.7
Reversed repetitive part	3284.3	5409.6	2333.0	7742.6	57.5
Progressive part	2514.9	5596.1	1536.4	7132.5	64.7
(Last Three Correct Runs on Part Combinations Excluded)					
Pure part	3549.0	750.1	3128.9	3879.0	8.5%
Direct repetitive part	1667.5	934.4	1158.1	2092.5	15.5
Reversed repetitive part	3284.3	3593.6	2333.0	5926.6	27.7
Progressive part	2514.9	2899.5	1536.4	4435.9	43.3

learning, the total pattern was broken up into parts and then again combined into the whole, the mastery of the maze required the expenditure of more energy than when the pattern was kept unbroken throughout the learning period. It is true that, excepting in Maze PW VI learned by the pure part procedure, there was an actual saving in the amount of energy required to master each maze as a whole by having first learned the parts; that is, the subjects of the part groups, after the parts had been mastered, spent less energy on the whole maze than did the subjects of the whole groups. When total energy spent is considered, however, there was actual waste in learning by the part methods in comparison with the whole method, as is shown in the table above.

The order of effectiveness of the procedures tested is somewhat different from the order obtained in the animal study. It will be observed that the position of methods 2 and 3 and of methods 4 and 5 are reversed in the two studies. This

Order for humans	*Order for animals*	
1. Whole	Whole	
2. Pure part	Direct repetitive part	Small difference
3. Direct repetitive part	Pure part	
4. Reversed repetitive part	Progressive part	Small difference
5. Progressive part	Reversed repetitive part	

may probably be accounted for by the experience of those subjects who in the repetitive part and progressive part procedures found recognition of some similarity in part combinations confusing enough to more than offset the advantage of learning in a forward direction. This was particularly true of the progressive part procedure in which the task was divided into the largest number of separate learning acts. As in the animal study, it was found that with trained subjects there was no evidence of progressively increasing facility in mastering maze patterns of comparable difficulty, and that the learning of one maze or part of a maze, when unique in character, did not affect either positively or negatively the learning of later mazes.

The results obtained and the conclusions reached are in agreement with the findings of many other investigators who have used human subjects in learning problems, but they differ from the findings of some who have used motor learning material, notably from those of Pechstein. In the report of the animal study the writer compared that investigation with the investigation of Pechstein, pointing out the differences in conditions which might explain the differences in results. All of those differences and more obtained in the present study when it is compared with that of Pechstein.

The last item, orientation of the subject in relation to the

Pechstein's study	*Present study*
a. High degree of similarity in the parts of the maze.	Each part of each maze unique in character.
b. Maze and each part of maze too small to constitute a real learning problem.	Large mazes.
c. Same principle operative at all places of choice between turns.	No uniform principle of turns or choices.
d. Untrained subjects.	Trained subjects.
e. No account taken of individual differences.	Individual differences equalized by having each subject learn by each procedure in each test.
f. Fixed position of each subject in relation to maze (pencil maze used).	Changing positional relationships of subject and maze comparable to changing relationships of rats to maze paths.

maze, has been shown by Perkins [3] to be of such significance that this one difference alone renders the present investigation and that of Pechstein incomparable. The writer wishes merely to point out that the whole procedure, which Pechstein found least effective, proved again in this study, as in the animal study, to be the most effective method of learning.

Summarizing the results of the experiments included in this investigation we find that

1. In learning maze patterns the whole method proved to be superior to all the part methods tested.

2. Of methods tested, the order of effectiveness from greatest to least was whole, pure part, direct repetitive part, reversed repetitive part, and progressive part.

3. Mastery of parts or part combinations first did contribute to mastery of the whole later, but not enough to compensate for the extra energy spent in learning the parts.

4. Some important factors causing waste in part learning were

a. Disturbance of the unity of the total pattern.

b. Confusion of subjects following recognition of relationship between parts learned separately or in combinations smaller than the whole.

c. Increase in the number of separate learning acts involved.

5. Parts learned separately, when required to function with other already-learned parts, required practice for mastery in the new situation.

6. Trained subjects showed fairly uniform learning ability throughout the entire problem.

7. The mastery of one part or maze, when unique in character, did not affect the mastery of any other.

(Manuscript received July 13, 1933)

[3] Perkins, N. L., Human Reactions in a Maze of Fixed Orientation. *Compar. Psychol. Monog.*, 1927, 4, No. 21.

RELATIVE SEATING POSITION AND ABILITY TO REPRODUCE DISCONNECTED WORD LISTS AFTER SHORT INTERVALS OF TIME [1]

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I. Need of Study

It appears, after a rather thorough examination of the literature dealing with techniques in connection with the problem of ability to reproduce disconnected series lists, that checks upon efficiency of relative seating positions either for auditory or for visual presentations have never been made. But a very short experience with the presentation of such lists, in a group situation, is enough to justify one in raising a serious question regarding this influence. Consequently, a report of the consideration given this problem as a part of a larger experimental series by the present investigator should not come amiss, either with reference to its apparent technical value or with regard to whatever theoretical worth it may have.

II. General Problem and Method of Approach

The general problem considered was that of the development of auditory impressionability measured by the ability to reproduce disconnected series lists.

A. The Lists Used

In the study of this problem, words either one syllable, two syllables, or three syllables in length, of known difficulty, and of known familiarity were selected by random sampling methods and arranged in lists of 2, 4, 6, 8, 10, and 12 words each in

[1] This research project was financed by the Payne Fund from money made available for the promotion of research on problems of radio education by the Bureau of Educational Research at Ohio State University. The contribution which the full study makes to radio techniques is presented in the article: 'Memory Span for Words Presented Auditorially,' by S. W. Calhoon and F. H. Lumley, to appear in the *Journal of Applied Psychology*.

such a manner that (1) no two words beginning with the same initial letter occurred in the same list, (2) no two succeeding words in a list ended with the same last two letters, (3) no two words having obvious associations, as 'book' and 'read,' were included in the same list, and (4) no distinction of grammatical differences between words employed was made. These word lists were then grouped by chance order into two sets of three tests each, one set to be used in the Lower Grades (3, 4, 5, and 6) and the other set to be employed in examining Higher Grades (7–12). Each of the three Lower Grade tests consisted of one list each of 4, 6, 8, and 10 one-syllable words; 2, 4, 6, and 8 two syllable words; and 2, 4, and 6 three-syllable words; in all, eleven lists arranged in random order within the test. The Higher Grade tests were of the same type except that a twelve-word list of one-syllable words was added and four-syllable word lists were used rather than three-syllable lists. This made for the Higher Grades, twelve lists to a test.

B. The Presentation

These three tests were then presented auditorially, a list at a time, by the experimenter, who was seated at the rear-center of the room, at intervals of one second, two seconds, or three seconds between words throughout a test as the case might be, with a standard time intervening for the auditors to write back as many words as they could. Timing was so devised that practice effects for various rates were made constant and the lists within a test were so arranged as to balance practice from list to list. A dictaphone record was made of all pronunciation-periods and writing-periods and the records subsequently checked for errors in timing.

C. The Seating Index

At the beginning of the series, a number was given each pupil in the room. He was asked to take the same seat at every experimental session and to place his number on every blank that he used during the day. The teacher then placed the numbers of the different pupils in the proper blanks upon a special "Seating Index Map" to indicate the position of each pupil relative to the experimenter. Subsequently the experimenter treated the Seating Index Maps in such a manner as to count in the first zone, all those within an area enclosed by an arc with a radius of two seats directly ahead of him and from the center of his seat as an origin, those within the next two seats' area, in the second zone, etc. All those beyond the fourth zone were in the fifth zone. This included an additional distance of more than two seats but once. Those seats falling more than half way in a zone were counted in that zone; those falling just half in one zone and half in another, were counted in the nearer zone, with reference to the experimenter. Each pupil was then given a Seating Index number corresponding to the number of the zone in which he sat.

D. The Number of Subjects Tested

By this method, reproduced lists were collected from 489 subjects for various lists of one-, two-, three-, and four-syllable words at one second, from 657 subjects for the same kinds of lists at two-second interval, and from 560 pupils for lists at the three-second rate. These lists were then scored according to a standard key and by standard rules and the data compiled and tabulated after the following manner.

III. Treatment of Data and Results

A. Derivation of Quantities

Distribution of the scores in number of words rightly reproduced, were made for varying list and syllabic lengths, the data being compiled with reference to Seating Index, and data for Grades 3, 4, 5, and 6 being combined in one set of distributions. Similar distributions were made of the combined data from Grades 7, 8, and 9, and from Grades 10, 11, and 12. This was done for words at one-second, at two-second, and at three-second intervals. The results for one-syllable and for three-syllable words, at one, two, and three seconds, are presented in Tables I, II, and III of this report.

B. Reading of Tables I, II, and III

These tables are read after the following manner:

(1) There are four groups of data presented in each table, all with reference to different lengths of one- and three-syllable words. There is the data for Lower Grades (3, 4, 5, and 6) at Seating Indices 1, 2, 3, 4, and 5. Then there is the data for the same sort of lists at the same rate, for Grades 7, 8, and 9, the second group. The third group is the same kind of data for Grades 10, 11, and 12, while the fourth group is made up of Means from combined distributions of the first three groups.

(2) Now the quantity 3.0, after the notation '4–1 Syllable,' under Seating Index 1, for Grades 3, 4, 5, and 6, means that all third, fourth, fifth, and sixth graders sitting near enough to the experimenter to be classed in Seating Index 1, of which there were 40, were able to reproduce a mean of 3.0 words out of the four words pronounced. Those in Seating Index 2, of whom there were 70, were able to reproduce a mean of 3.1 words, under the same conditions, the 70 pupils in Seating Index 3 could produce 2.7 words, etc. Similarly, seventh, eighth, and ninth Graders in Index 1, and of whom there were 22, were able to reproduce a Mean of 3.6 words, and thus on through the tables.

TABLE I

RELATION BETWEEN POSITION IN ROOM AND ABILITY TO REPRODUCE WORDS

(Words at 1 Second)

Nature of Lists	Number of Words Reproduced																			
4–1 Syl.	3.0	3.1	2.7	2.8	2.4	3.6	3.2	3.3	3.5	4.0	3.9	3.9	3.8	4.0	3.5	3.3	3.2	3.1	3.1	2.9
6–1 Syl.	2.9	2.8	2.8	2.6	2.5	3.7	3.5	3.6	3.6	4.3	4.1	4.1	4.3	3.8	4.5	3.4	3.2	3.3	3.0	3.1
8–1 Syl.	3.0	2.9	2.6	2.7	2.1	3.7	3.8	3.6	3.6	3.9	4.3	3.9	4.0	4.0	5.0	3.6	3.3	3.2	3.1	2.6
10–1 Syl.	3.2	3.5	3.3	2.8	2.9	3.7	3.7	3.4	3.8	3.3	3.8	4.2	4.0	3.3	5.0	3.7	3.6	3.3	3.2	3.0
12–1 Syl.						4.1	4.0	3.4	4.0	4.3	4.3	4.3	4.1	4.7	5.0	4.1	4.1	3.7	4.1	4.4
2–3 Syl.	1.6	2.0	1.6	1.5	1.5	2.0	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.8	1.8	1.8	1.7	1.7
4–3 Syl.	1.7	2.3	2.2	2.1	2.2	2.8	3.2	2.9	2.9	2.9	3.1	3.3	3.1	3.3	3.5	2.4	2.7	2.5	2.4	2.2
6–3 Syl.	2.4	2.3	2.2	2.3	2.2	3.0	3.2	2.9	3.3	3.9	3.8	3.7	3.8	3.8	3.5	2.9	2.8	2.6	2.7	2.7
8–3 Syl.						3.3	3.2	3.1	3.4	3.5	3.7	3.6	3.8	3.8	3.5	3.5	3.4	3.4	3.5	3.5
Index	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Number of Cases	40	70	70	70	24	22	31	38	36	8	18	27	21	6	2	80	134	128	112	33
Grades	3, 4, 5, 6					7, 8, 9					10, 11, 12					All Grades*				

* These and all other averages are computed on the basis of two decimal places. The second decimal place has been dropped in these tables to enable the reader to follow the trends more easily.

TABLE II

RELATION BETWEEN POSITION IN ROOM AND ABILITY TO REPRODUCE WORDS

(Words at 2 Seconds)

Nature of Lists	Number of Words Reproduced																			
4–1 Syl.	3.1	3.1	3.0	2.8	3.1	3.5	3.4	3.2	3.4	3.6	3.7	3.8	3.6	3.6	4.0	3.4	3.3	3.1	3.1	3.2
6–1 Syl.	3.0	3.3	2.9	2.9	2.8	3.6	3.3	3.5	3.5	3.2	4.2	4.0	4.0	4.0	5.0	3.5	3.4	3.3	3.2	2.9
8–1 Syl.	3.0	3.2	3.0	2.9	2.6	4.1	3.7	3.9	4.1	4.8	4.5	4.3	4.5	3.4	5.0	3.6	3.5	3.5	3.1	2.8
10–1 Syl.	3.2	3.1	3.2	3.0	2.8	4.1	3.8	3.8	4.0	3.0	4.5	4.1	4.0	3.6	3.0	3.8	3.5	3.5	3.4	2.8
12–1 Syl.						4.3	4.2	4.2	4.2	4.8	4.6	4.8	4.9	4.5	5.0	4.4	4.4	4.4	4.2	4.8
2–3 Syl.	1.8	1.7	1.7	1.7	1.7	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	2.0	1.9	1.8	1.8	1.8	1.7
4–3 Syl.	2.2	2.2	2.0	2.1	1.9	2.9	2.9	2.9	3.1	2.8	3.3	3.3	3.2	3.1	4.0	2.6	2.6	2.5	2.6	2.2
6–3 Syl.	2.8	2.9	2.6	2.6	2.1	3.2	2.9	3.0	3.1	3.2	3.4	3.3	3.8	3.2	4.0	3.0	2.9	2.9	2.8	2.3
8–3 Syl.						3.5	3.4	3.7	3.6	2.8	4.1	4.2	3.5	4.0	4.0	3.7	3.7	3.6	3.6	3.0
Index	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Number of Cases	59	97	94	73	29	40	60	60	49	5	28	29	23	11	1	127	186	179	133	35
Grades	3, 4, 5, 6					7, 8, 9					10, 11, 12					All Grades				

TABLE III

RELATION BETWEEN POSITION IN ROOM AND ABILITY TO REPRODUCE WORDS

(Words at 3 Seconds)

Nature of Lists	Number of Words Reproduced																			
4–1 Syl.	3.1	2.9	2.9	3.0		3.7	3.5	3.5	3.5		3.5	3.7	3.8	3.7		3.4	3.3	3.3	3.3	
6–1 Syl.	3.0	3.2	3.0	3.2		4.1	4.1	4.2	3.9		4.2	4.6	4.7	4.5		3.7	3.7	3.7	3.6	
8–1 Syl.	2.9	3.0	2.9	2.8		4.1	3.8	3.9	4.3		4.6	4.7	4.5	3.6		3.7	3.5	3.5	3.5	
10–1 Syl.	3.3	3.8	3.7	3.3		4.5	4.1	4.1	4.2		4.5	4.7	4.5	4.2		3.9	4.1	3.9	3.8	
12–1 Syl.						4.5	4.6	4.7	4.5		5.4	4.8	4.9	5.0		5.4	4.7	4.8	4.7	
2–3 Syl.	1.6	1.7	1.5	1.4		2.0	2.0	2.0	2.0		2.0	2.0	2.0	2.0		1.8	1.8	1.8	1.7	
4–3 Syl.	2.2	2.5	2.0	2.1		3.4	3.1	3.3	3.2		3.5	3.4	3.6	3.2		2.9	2.8	2.7	2.7	
6–3 Syl.	2.5	2.7	2.4	2.5		3.8	3.5	3.6	3.6		4.1	4.1	4.2	4.0		3.2	3.2	3.1	3.1	
8–3 Syl.						3.8	3.5	3.6	3.9		4.0	4.3	4.3	4.0		3.8	3.8	3.8	3.9	
Index	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Number of Cases	51	87	80	58		34	57	61	50		23	26	24	9		108	171	164	117	
Grades	3, 4, 5, 6					7, 8, 9					10, 11, 12					All Grades				

C. Construction of Table IV

Because of considerations which will be pointed out a little later, Table IV was constructed by computing the Mean of all word-list-length Means, that is, the Mean of all the means for various-lengthed lists of a specific syllabic nature, under various Seating Indices for various grade groups, at all times, for the two syllabic lengths reported here. Thus, the quantity 3.0, falling under Index 1, for third, fourth, fifth, and sixth Grades, and after the one-second interval, for one-syllable words, is an average of the Means for list lengths 4, 6, 8, 10, and 12, of one-syllable words, at that Grade level, and for Seating Index 1, as recorded in Table I. Similarly the quantity 3.1, just to the right of the quantity 3.0 from Table IV, is the average of all Means for various list lengths of one-syllable words, for the same grades under Seating Index 2, of Table I. Thus were all the values for Table IV computed.

D. Reading Table IV

In reading Table IV, then, we would say that all third, fourth, fifth, and sixth graders, sitting within the distance of Index 1, from the experimenter, were able to reproduce a Mean of 3.0 one-syllable words when these words were pronounced at the rate of one a second. Thus, also, third, fourth, fifth, and sixth graders, seated at a distance of Index 2, were able to reproduce a Mean of 3.1 one-syllable words, pronounced at the rate of one a second. Similarly, tenth, eleventh, and twelfth graders, sitting in a position indicated by Index 3, were able to write a Mean of 4.5 one-syllable words when words were pronounced at the rate of one every three seconds. And in a like manner, should all the quantities of the table be read.

E. Graphical Representations

Figures 1–8, in Plates I and II, are plottings of the data of Table IV.

IV. Discussion and Conclusions

A discussion of this data can most directly be approached by pointing out, first, certain general observations with regard to the data presented.

TABLE IV

RELATION BETWEEN POSITION IN ROOM AND ABILITY TO REPRODUCE WORDS

Mean Reproduction for all List Lengths

(Summary)

Nature of Lists		Number of Words Reproduced																			
Syllable Length	Interval																				
1	1″	3.0	3.1	2.8	2.7	2.5	3.8	3.7	3.5	3.7	3.9	4.1	4.1	4.0	4.0	4.8	3.6	3.5	3.3	3.3	3.2
	2″	3.1	3.2	3.0	2.9	2.8	3.9	3.7	3.7	3.8	3.9	4.2	4.2	4.2	3.8	4.4	3.7	3.6	3.5	3.4	3.1
	3″	3.1	3.2	3.1	3.1		4.0	4.1	4.1	4.1		4.5	4.5	4.5	4.2		4.0	3.9	3.9	3.8	
3	1″	1.9	2.2	2.0	2.0	2.0	2.8	2.9	2.7	2.9	3.1	3.1	3.2	3.1	3.3	3.1	2.6	2.7	2.6	2.6	2.5
	2″	2.3	2.3	2.1	2.1	1.9	2.6	2.8	2.9	2.9	2.7	3.2	3.2	3.1	3.1	3.5	2.8	2.8	2.7	2.7	2.3
	3″	2.1	2.3	2.0	2.0		3.2	3.0	3.1	3.2		3.4	3.4	3.5	3.3		2.9	2.9	2.9	2.8	
Index		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Grades		3, 4, 5, 6					7, 8, 9					10, 11, 12					All Grades				

1. Irregularities evident, at the ordinates of Seating Indices 4 and 5, when the data of Tables I, II, and III, derived from one-syllable words for (*a*) seventh, eighth, and ninth graders at one second, (*b*) tenth, eleventh, and twelfth graders at one second, (*c*) seventh, eighth, and ninth graders at two seconds, (*d*) tenth, eleventh, and twelfth graders at two seconds, and (*e*) tenth, eleventh, and twelfth graders at three seconds, are plotted (though they are not plotted here), are no doubt to be explained largely in terms of sampling errors, since at every one of these points, less than ten subjects are involved, while the Median of subjects employed at every Seating Index point, for each rate and for each group within a rate, is fifty. Though these plottings are not presented in this paper, an examination of the Tables I, II, and III will verify this statement. Other outstanding irregularities are not apparent.

2. Data is not reported for Seating Index 5, at the three-second interval, in any grade group (See Table III) because there were not enough cases to justify any conclusion whatsoever. These curves, in Plates I and II, are therefore not completed.

3. The consistently lower Means for 4-word lists of one-syllable word (*a*) in the seventh, eighth and ninth grades at one-second, (*b*) in the tenth, eleventh, and twelfth grades at two-seconds, (*c*) in the seventh, eighth, and ninth grades at three-seconds and (*d*) in the tenth, eleventh, and twelfth grades at three-seconds (Tables I, II, and III) are undoubtedly due to the limiting nature of the list length itself.

When these three considerations are observed and curves resultant to the plotting of the data of Tables I, II, and III, adjusted in their light, we quickly see that the trend of all the curves in a group of various list lengths is so unified as to render a single curve, made up of the averages of all the Means for the various list lengths for specific Seating Indices at specific grade-group levels, not inaccurately representative of each family's trend. If this combination were made, all word list lengths for a certain grade-group with reference to Seating Index, and for specific times, would be expressed in a

PLATE I

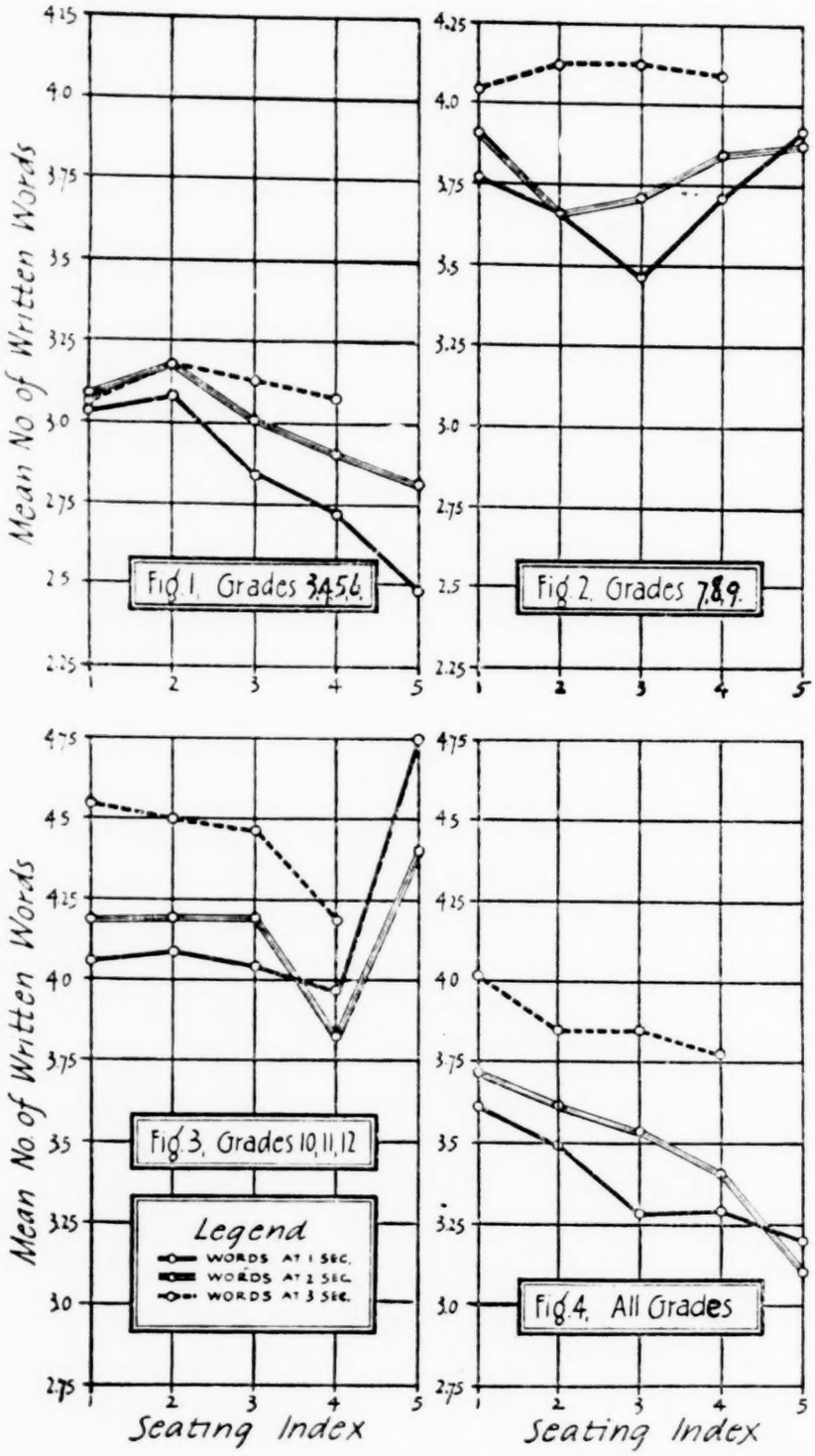
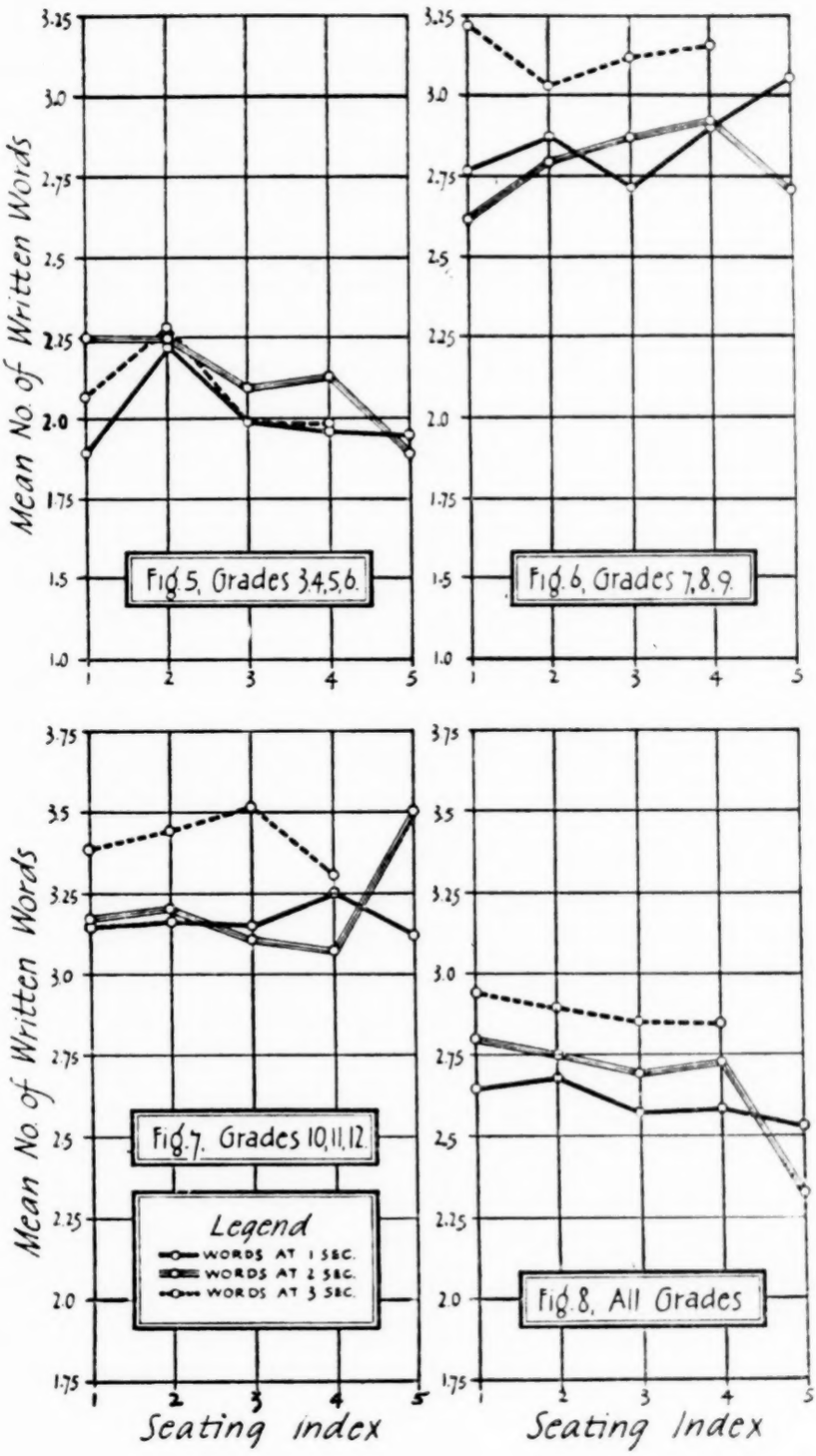

Mean No of Written Words
Fig 1. Grades 3,4,5,6.
Fig 2. Grades 7,8,9.
Fig 3. Grades 10,11,12
Fig 4. All Grades
Legend
WORDS AT 1 SEC.
WORDS AT 2 SEC.
WORDS AT 3 SEC.
Seating Index
Seating Index

PLATE II


Mean No. of Written Words
Fig. 5, Grades 3,4,5,6.
Fig. 6, Grades 7,8,9.
Fig. 7, Grades 10,11,12.
Fig. 8, All Grades
Legend
WORDS AT 1 SEC.
WORDS AT 2 SEC.
WORDS AT 3 SEC.
Seating Index
Seating Index

single family of three curves. And from the four families of curves for one-syllable words thus formed (Table IV and Plate I) and from the four comparable families for three-syllable words (Table IV and Plate II) certain highly interesting and very valuable trends could be described.

1. There is an influence of position in the room upon ability of the subjects to write words which is in an inverse relation to the length of the words pronounced. This is very prominent in the third, fourth, fifth, and sixth grade group.

A glance at Fig. 1 will show that there is a difference of about 0.6 of a word for words at one second, between the Mean for all length lists at Seating Index 1 and the similar Mean for Seating Index 5. A glance at Fig. 5 will show a difference of about 0.1 of a word and the general trend of all the curves in this Figure to be nearly horizontal. But looking again at Fig. 1, we see that the differences between Seating Index 1 and Seating Index 5 for words at two seconds and for words at three seconds are about 0.3 of a word and 0.1 of a word respectively. This difference is greater between Seating Index 2 and Seating Index 5. Seating Index 2 in both syllabic lengths, seems to be the most convenient and efficient location for the writing back of words pronounced.

That this difference is not due to a difference in grade arrangement of seating in the room is evident from the fact that seating is by grades in the rows from front to back, one grade being either to the right or to the left of the experimenter and not either nearer or farther from him. That it could not be due to a difference in intelligence seems apparent from the fact that the seats were in every case assigned to the pupils, generally in alphabetical order, in the Lower Grades. And in the Higher Grades, care was taken that classes should be systematically mixed throughout the room. This was either done by the experimenter or by the teacher, from alphabetical considerations and therefore without reference to ability.

Further, the influence manifests itself upon one-syllable words most prominently and at one second most definitely, leading one to believe that the influence must be one of under-

standability of the words pronounced or a reduction of efficiency in memory due to a greater requirement for energy in understanding the words pronounced. This seems confirmed by the second observation, cited below.

That it could not be due to errors in timing the presentation of the lists is evidenced by the fact that a study of timing errors made, later to be reported more fully, shows that a Mean error of only 3 percent with an Inter-Quartile range of 5.6 percent was made in the pronunciation of all lists.

2. There is an inverse relationship between rate of pronunciation and influence of seating, in the Lower Grades, when one-syllable words are pronounced. This is distinctly shown in Fig. 1, where the greatest influence is on words at one second and the influence constantly becomes less, inversely in relation to the interval between the words pronounced. It would seem, from this, that the longer time gave more opportunity for those who could not hear as well to compensate by something of the nature of 'perceptual filling.'

That 'perceptual filling' has a definite place seems evident also from the fact that the number of three-syllable words reproduced, in the perception of which its influence could much more manifestly be exerted, show no distinct influence from Seating Index, outside of the one case, in the Lower Grades, at Seating Index 2, previously cited. Further,

3. Higher Grades, 7–12, are little or not at all influenced by seating with reference to the number of one-syllable words reproduced (Figs. 2 and 3). This statement should be qualified only to the extent that words at one second and at two seconds show a greater efficiency at Seating Indices 2 and 3. (For words at one second, Seating Index 3 is distinctly the best.) Neither are these Higher Grades influenced perceptibly by Seating Index for three-syllable words (Figs. 5 and 6).

4. Consideration of Figs. 4 and 8 will show conclusively the difference between the influence of Seating Index for one- and for three-syllable words because these Figures report results from between 300 and 400 individual cases studied at every Seating Index point.

Where in Fig. 4, in one-syllable words, there is a drop of

from 0.3 to 1.1 words between Seating Index 1 and Seating Index 5, in Fig. 8, in three-syllable words, the drop varies .2 to .5 of a word. Or, roughly, there is twice the influence of Seating on one-syllable words that there is for those with three syllables.

V. Summary

Consequently, we may summarize by concluding:

1. That there is, in the third-, fourth-, fifth- and sixth-grade groups, a distinct influence of relative seating position upon Mean number of one-syllable words written, which is in an inverse relationship to the length of interval between the words and in direct relation to the distance which the pupil is from the speaker.

2. That there is an inverse relation between Developmental Index (Mean Grade-Age) and influence of Seating which has become very small by the eighth grade—so small as to have become largely imperceptible by the technique of this experiment.

3. That there is a similar relation in a very much reduced degree, for three-syllable words which would indicate an inverse relation between Syllabic Length and influence of Seating Index when time remains constant.

4. That these considerations all point to the influence and facilation of 'perceptual filling' directly proportional to Developmental Index and directly proportional also to the length of the interval elapsing from word to word.

5. That this Seating Index Variation must be taken into consideration when the comparative ability of pupils to recall one-, two-, three-, and four-syllable words is being in any way finally considered.

(Manuscript received June 11, 1934)

INFLUENCE OF LENGTH OF LISTS UPON ABILITY IMMEDIATELY TO REPRODUCE DISCONNECTED WORD-SERIES AUDITORIALLY PRESENTED [1]

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I. Preliminary Considerations

The purpose of this paper is to present certain introductory remarks, together with a more exhaustive report upon a certain phase of the problem of auditory impressionability. The data reported bear upon the question: What is the influence of the length of disconnected word lists upon ability immediately to reproduce the items given?

By the term *auditory impressionability* is meant that intrinsic tendency which the organism has to receive behavioral modifications through the ear.

In a study of auditory impressionability, by the reproduction of disconnected item-series technique, there are a number of concrete variables to be described and controlled.

1. *Familiarity* of the items in the disconnected series must be assured. That is, each item in every list utilized must be definitely known to be, under the conditions in which it is employed, a part of the common stock of tools or instruments with which the subject being tested has habitual intercourse.

2. The *Mechanical Difficulty* of the items must be such that the subject is able to write back at least a very high percentage of them when memory, as a factor, is removed. If the subjects are to be tested by verbal report, the items used must be common to the speaking vocabularies of the subjects.

[1] This research project was financed by the Payne Fund from money made available for the promotion of research on problems of radio education in the Bureau of Educational Research at Ohio State University. The contribution which the full study makes to radio techniques is presented in the article: 'Memory Span for Words Presented Auditorially,' by F. H. Lumley and S. W. Calhoon, to be published in *The Journal of Applied Psychology*.

3. *Coefficients of Associability*, that is, the degree of "togetherwardness" among the individual items of the experimental series utilized must be either definitely known or carefully considered in all conclusions drawn as the result of the use of any experimental item-series.

4. *Variations in Timing* the list presentations must be carefully controlled and rigorously checked.

5. The *Objective Stimulus Values* of the various presentations of the series lists must be equalized in as far as it is practically possible. In other words, one list of items must not be more clearly impressed upon the subject than another because of variation in the mode of presenting the lists.

6. The *Environmental Background* of the tests must be constant. That is, there must be a total situation created by an habituated environment free from physical disruptions, thermal, tactual, auditory or visual, and combined with an activity set as nearly the same as possible, from experimental period to period, and from group to group.

With these six variables held constant, tests may be devised to study the influence of a number of other variables, controlling them all and going from one to the other as we will. Thus we could consider, among other problems,

(1) The Influence of Organismic Set on Impressionability.
(2) The Influence of Relative Seating Position on Impressionability.
(3) The Influence of Length of Series on Impressionability.
(4) The Influence of Nature of Series on Impressionability.
(5) The Influence of Learning on Impressionability.
(6) The Influence of Rate of Presentation on Impressionability.
(7) The Influence of Organismic Developmental Maturity on Impressionability.

II. Other Investigations

An examination of the work of previous investigators shows in many cases a lack of control with reference to at least one of those variables cited and often with reference to a number of them. Jacob's work (**10**) was not reported at

sufficient length to show, satisfactorily, the extent of his controls. Bolton (**2**) did not carefully enough control rate of presentation. Münsterberg and Bingham (**12**) did not control the influence of list length, or variations in rate of presentation and used a biased sampling of subjects. Kirkpatrick (**11**) did not adequately control a number of the most important variables. Smedley (**14**) did not control practice effect, nor effect of limiting list length. Calkins (**5**) failed to control intensity of stimulus and collected data from a very biased population. Winch (**17**) unquestionably demonstrated distinct practice effects but showed them to be more apparent from day to day than for different periods within a day. Bergström (**1**) showed clearly the presence of a differential influence of rate of presentation upon impressionability with reference to kinds of items employed. Weidensall (**16**) found in a rather poorly controlled experiment that report by the voice has more of a disruptive effect in testing than the writing of the words, at least for criminal women. Gates (**8**) does not seem successfully to have equated methods of list presentations. Guilford and Dallenbach (**9**) failed adequately to consider list length in their experimentation, as will later be pointed out. Davis (**7**) and Sauer (**13**) have shown no practical difference between dissociated words and nonsense syllables for use in memory experiments. And Calhoon (**4**) has shown the definite influence, at certain ages, in group experiments, of seating position upon impressionability.

Consequently, it appears as an outgrowth of this previous experimentation that the way has been fairly well cleared for a carefully controlled experiment, observing and considering each of these variables in turn, and studying thereby the changes in auditory impressionability with changes in the various environmental conditions. An attempt in that direction has been made by the present investigator, one phase of which is reported here; another phase has already been reported (4), and others will follow.

III. Method

After more than six months of preliminary experimentation, during which techniques were developed and discarded and others built up, the following plan was evolved and followed throughout the major experimental series.

1. Such arrangements were made, through school principals, with the teachers, that each teacher knew at exactly what time the experimenter would be in a room, what he would do, the nature of his problem, and the teacher's duty with reference to it. This routine phase was so well carried out that the experiment ran through at least fifteen days, in seven different schools, in six different counties in Central Ohio, without a serious delay and the experimenter was able to enter every room promptly at the time scheduled. The process was quiet, systematic, and routine throughout.

2. The experimenter carried with him, from room to room, only a small bound book of *Directions and Tests* and a dictaphone with which pupils were familiar before it was used. Consequently pupils were not disturbed at any time by a noisy entrance. The entire room was generally at work again within a few moments after the experimenter's entrance.

3. The pupils in two rooms were tested per day. No Lower-Grade room (grades 3-6), was tested the same day with a Higher-Grade room (grades 7-12), so that the Lower-Grade technique was not confused with the Higher. Five tests were given in each room. The first lasted a half hour and the other four each fifteen minutes, with a fifteen minutes' rest for the experimenter between tests. Consequently at least a half hour always elapsed between visits to a room.

4. At the first visit to each room the dictaphone was explained to the pupils, its use demonstrated, and then it was allowed to stand idle while the experimenter gave a 50-word Spelling test to the pupils of the room. This test was made up of words selected from Tidyman's list (15), which he reports to be used "quite definitely" by third graders. From this same list, the Lower-Grades Word-Tests were constructed. Each word was pronounced twice in the spelling test, in a quiet but firm tone of voice, such that all gave evidence of hearing either with the first or second pronunciations.

5. Each of the next three 15-minute sessions in a room were employed in the pronunciation of word lists at varying rates and in different orders, so that practice effects from rate to rate and from list to list within a test might be balanced. Standard times, previously determined by experimentation, were allowed for the writing of all lists. The pronunciation and writing of all lists were recorded on dictaphone records and later checked, throughout, for errors in timing.

6. Different lists of words were used in each of the three tests. No word was used twice in the entire experiment. Three lists each of 4, 6, 8, and 10, one-syllable words, three lists each of 2, 4, 6, and 8, two-syllable words, and three lists each of 2, 4, and 6, three-syllable words were selected from Tidyman's third-grade list, by random sampling methods, and arranged in such an order that (1) there was no initial alphabetical succession and no initial duplication within a list, (2) no two succeeding words ended in the same two letters, (3) no distinction with reference to grammatical form was made, and (4) no obvious relationships such as 'book' and 'read' were allowed within a list. These lists were then arranged into three tests of eleven lists each, one of each type to a test. The lists were arranged in chance order but retained the same order from test to test. These tests were used in all Lower-Grades sessions.

7. Similar lists were constructed for Higher Grades from words reported by Dale (6) to be recognized by 95 per cent of sixth graders. These tests had also a list of 12 one-syllable words, and four-syllable words were employed rather than the three-syllable words of the Lower Grades. The Higher-Grade tests therefore had twelve lists each.

8. The lists on these tests were given, a full test at a certain rate, either at one word per second, one word per two seconds, or one word every three seconds. Each

list was introduced with the signal 'Pencils up!' 'Ready,' and closed with the signal 'Now' when pupils began to write. The words 'Ready' and 'Now' were pronounced in the same rhythm as the list. The lists were pronounced with a rising accent on each word and a falling accent on the 'Now.' They were pronounced in a quiet, firm, distinct tone of voice which was routine and monotonous, almost continually, throughout. Pupils sat with pencils up, elbows resting easily on desks, all pupils looking toward the front continually and with instructions that mouths be tightly closed throughout the pronunciations. The experimenter sat in the rear-center of the room throughout the sessions and spoke into the dictaphone throughout these three tests, at such an angle that his voice was unobstructed as it went into the room.

(9) Timing was controlled by rhythms secured from the second hand of the experimenter's watch and practiced, generally, throughout the writing periods between the lists. Writing periods were closed by the signal 'Pencils up!' All directions were read. At the close of the experimental session, the experimenter merely withdrew with his dictaphone. The teacher took up the papers systematically and all papers and dictaphone records were removed from the room at the close of the day.

(10) Pupils were merely instructed to write as many words as they could remember. No reference was made to order of reproduction.

(11) The Fifth Experimental period was otherwise employed and will be reported later.

(12) Data was thus gathered in seven schools in six different counties in central Ohio, covering a total of 946 pupils distributed quite evenly through the grades from three to twelve.

IV. Control of Variables

1. *Familiarity* of words used is guaranteed by the fact that the Lower-Grade words were selected from lists voluntarily used by third-grade pupils in their own compositions. The Higher-Grade words were familiar to 95 percent of sixth graders and were not used until the seventh grade.

2. *Mechanical Difficulty* is shown to be controlled by the fact (See a study of the *Spelling Test*, on file with the complete data (3),) that the words used can be written intelligibly by at least 90 percent of third graders while about 56 percent are correctly spelled. However, laboriousness of writing and grotesquesness of spelling, in some cases, lead one to think that true curves for third graders and perhaps for fourth graders as well, should be a bit higher. There is no apparent difficulty above the fourth grade.

3. *Coefficients of Associability.* According to evidence on file with the complete report of the project (3), words entirely familiar, mechanically simple, syllabically homogeneous, non-alphabetically arranged, otherwise non-mechanically identifiable, and selected by random sampling methods, without

regard to grammatical characteristics, are not, thereby, necessarily made equally associable. And the results of this experiment have served very clearly to point out that fact. Consequently certain irregularities have, by this condition, been introduced to the data with the result that quantitative conclusions are, in some cases, impossible. Wherever this influence is present in the data of this study, it is carefully considered.

4. *Variations in Timing* the presentations have been shown (3) to be less than 14 percent, in 100 percent of the cases and to vary, within an Interquartile Range of 5.55 percent around 3.00 percent as a Mean. There was less error in timing the writing of the lists.

5. Evidence has also been brought forth (3) to show that the *Objective Stimulus Value* of the various presentations was probably as constant as it is possible for one to make it where lists are pronounced directly by the human voice, at each test.

6. *Environmental Surroundings* were also quite satisfactorily constant, due to a number of different reasons. Summarizing the discussion of this variable (3), we may say that the environment was so free from extraneous disturbances that use of a disturbance check list proved unnecessary. Disturbance sufficient to justify the invalidation of a word list occurred only once. The list was ruled out.

7. *Organismic Set* was assumed to be constant throughout. See discussion (3).

8. The influence of practice on the data reported here is equivalent to the influence on data for a similar group of pupils tested once after 18 lists of practice.

V. Treatment of Data and Results

The lists, written by the 946 subjects of this experiment for the three Memory Tests, were sorted and scored according to standard rules and by the use of standard scoring keys. The complete data from all the pupils in a room were then transferred to data assembly sheets, from which distributions were made of scores, in number of words reproduced, for one-second, two-second, and three-second intervals, for one-

syllable, two-syllable, three-syllable and four-syllable words, for varying list-lengths, at the different grade levels, from three to twelve. Distributions were also made of the ages to the nearest birthday of the subjects used for each type of list. From this large number of distributions, Arithmetical Means were taken and the data tabulated. These data are presented completely elsewhere (3).

In Tables I and II of this paper, are the results for one-syllable and for three-syllable words. Tables III and IV are presentations of the deviations for one-syllable and three-syllable words of the individual Means for each list length at a Grade-Age point, from the average number of words, regardless of list length reproduced at that Mean Grade Age. Table V is a summarizing table for results at all syllabic lengths. It is, in part, an extraction from raw data not reported here.

VI. Discussion and Conclusions

Horizontally, Tables I–IV are divided into three parts. The portion at the extreme left gives data for words presented at one-second intervals. The middle portion is for words at two seconds, and the right section for words at three-second intervals. Each section of Tables I–IV, is divided into columns to accomodate the various list lengths. Vertically, the Tables represent Means for various Mean Grade-Ages, as noted. The reading of Table V will be explained a bit later.

A comparative examination of the Means for four-word lists with Means for other lists at all intervals for one-syllable words (Table I) shows consistently smaller Means for the four-word lists. A similar comparison of Means for three-syllable words shows that same inferiority for both two- and four-word lists. There is no doubt but that this inferiority of two- and of four-word lists is due to the artificial limits of the word list lengths. Pupils did not reproduce more because there were not more words to be reproduced.

Consequently in computing the Means for all list lengths at a Grade-Age level, as presented in Tables III and IV, and in the same computations for two- and four-syllable words not reported here except in summary, two- and four-word lists

TABLE I

RELATION BETWEEN MEAN GRADE AGE AND NUMBER OF WORDS WRITTEN

(1-Syllable Words)

Words at: 1 Second						2 Seconds						3 Seconds					
Mean Grade Age	List Lengths					Mean Grade Age	List Lengths					Mean Grade Age	List Lengths				
	4	6	8	10	12		4	6	8	10	12		4	6	8	10	12
9.1	2.2	2.1	2.1	2.2		9.0	2.5	2.7	2.7	2.3		8.9	1.8	1.8	1.8	2.2	
10.5	2.6	2.7	3.1	2.9		10.4	2.8	2.9	3.1	2.9		10.0	2.8	2.9	2.7	3.2	
11.1	3.0	2.9	3.1	3.3		10.8	3.2	3.0	3.0	3.3		10.8	3.1	3.1	3.1	3.7	
12.4	3.5	3.3	3.3	4.1		12.1	3.3	3.4	3.3	3.7		12.0	3.5	3.9	3.4	4.3	
13.4	3.1	3.4	3.4	3.4	3.8	13.5	3.3	3.2	3.7	3.8	4.0	13.5	3.6	4.0	3.8	3.9	4.6
14.2	3.4	3.7	3.9	3.7	3.7	14.1	3.4	3.5	4.1	4.1	4.3	14.1	3.6	4.1	4.2	4.4	4.9
15.3	3.7	3.9	3.9	3.7	4.2	15.1	3.7	4.1		3.8	5.0	15.5	3.3	3.9	3.8	4.5	3.9
16.3	3.8	4.2	4.0	3.7	4.1	16.2	3.8	3.9	4.0	4.3	4.6	15.8	3.6	4.3	4.5	4.4	5.2
16.9	3.8	4.9	5.4	4.5	5.1	16.9	3.9	4.6	4.8	5.1	5.4	16.9	3.6	4.5	4.4	4.6	4.7
18.1	3.9	4.5	4.6	4.3	4.4	18.1	3.7	4.4	4.5	4.6	5.2	18.1	3.9	4.8	4.6	4.8	5.6
Average*	3.3	3.5	3.7	3.6	4.2	Average	3.4	3.6	3.7	3.8	4.8	Average	3.3	3.7	3.6	4.0	4.8

* These and all other averages are computed on the basis of two decimal places. The second decimal place has been dropped in these tables to enable the reader to follow the trends more easily.

TABLE II

RELATION BETWEEN MEAN GRADE AGE AND NUMBER OF WORDS WRITTEN
(3-Syllable Words)

Words at: 1 Second					2 Seconds					3 Seconds				
Mean Grade Age	List Lengths				Mean Grade Age	List Lengths				Mean Grade Age	List Lengths			
	2	4	6	8		2	4	6	8		2	4	6	8
9.1	1.3	1.8	1.7		9.0	1.4	1.5	2.1		8.9	.9	1.4	1.4	
10.5	1.5	2.0	2.0		10.4	1.7	1.9	2.3		10.0	1.5	2.0	2.4	
11.1	1.8	2.3	2.7		10.8	1.8	2.4	2.9		10.8	1.7	2.2	2.6	
12.4	1.9	2.6	3.0		12.1	1.9	2.5	3.2		12.0	1.8	2.7	3.1	
13.4	1.9	2.8	2.9	3.2	13.5	1.9	2.9	2.8	3.3	13.5	2.0	3.2	3.4	3.7
14.2	2.0	2.8	3.1	3.3	14.1	2.0	3.0	3.1	3.8	14.1	2.0	3.4	3.8	3.8
15.3	2.0	3.1	3.7	3.4	15.1	2.0	2.4	3.5	3.4	15.5	2.0	2.9	3.1	3.3
16.3	2.0	3.2	3.9	3.6	16.2	2.0	3.1	3.2	4.0	15.8	2.0	3.5	3.9	4.1
16.9	2.0	3.5	4.3	4.0	16.9	2.0	3.5	4.1	4.2	16.9	2.0	3.4	4.3	4.1
18.1	2.0	3.5	4.3	4.2	18.1	2.0	3.2	3.7	4.1	18.1	2.0	3.5	4.3	4.5
Average	1.8	2.8	3.1	3.6	Average	1.9	2.6	3.1	3.8	Average	1.8	2.8	3.2	3.9

TABLE III

DEVIATION OF INDIVIDUAL MEANS FROM MEANS FOR ALL LIST LENGTHS

(1-Syllable Words)

Words at: 1 Second							2 Seconds							3 Seconds						
Mean Gr. Age	Gen. Mean	Deviations for List Lengths					Mean Gr. Age	Gen. Mean	Deviations for List Lengths					Mean Gr. Age	Gen. Mean	Deviations for List Lengths				
		4	6	8	10	12			4	6	8	10	12			4	6	8	10	12
9.1	2.1	.1	.0	.0	.1		9.1	2.6	− .1	.1	.1	−.3		8.9	1.7	.1	.1	.1	.5	
10.5	2.9	− .3	−.2	.2	.0		10.3	3.0	− .2	−.1	.1	−.1		10.0	2.9	− .1	−.1	−.2	.3	
11.1	3.1	− .1	−.2	.0	.2		10.8	3.1	.1	−.1	−.1	.2		10.8	3.3	− .2	−.2	−.2	.4	
12.4	3.6	− .1	−.3	−.3	.5		12.1	3.4	− .1	−.1	−.2	.2		12.0	3.8	− .3	.0	−.5	.4	
Lower Gr. Av.		− .1	−.2	.0	.2		Lower Gr. Av.		− .1	.0	.0	.0		Lower Gr. Av.		− .1	.0	−.2	.4	
13.4	3.5	− .4	−.1	−.1	−.1	.3	13.5	3.7	− .4	−.5	.0	.1	.3	13.5	4.1	− .5	−.1	−.3	−.2	.6
14.2	3.8	− .4	.0	.1	.0	.0	14.1	4.0	− .6	−.5	.1	.1	.3	14.1	4.4	− .8	−.3	−.2	.0	.5
15.3	3.9	− .2	.0	.0	−.2	.3	15.6	4.2	− .6	−.2	.0	−.5	.8	15.5	4.0	− .8	−.1	−.3	.5	−.1
16.3	4.0	− .2	.2	.0	−.3	.1	16.2	4.2	− .4	−.3	−.2	.1	.4	15.8	4.6	−1.0	−.3	−.1	−.2	.5
16.9	5.0	−1.2	−.1	.4	−.5	.2	16.9	5.0	−1.1	−.3	−.2	.1	.4	16.9	4.4	− .9	.1	−.1	.2	.2
18.1	4.4	− .5	.0	.1	−.1	.0	18.0	4.7	− .9	−.3	−.2	−.1	.5	18.1	4.9	−1.0	−.2	−.3	−.2	.7
Total Av.	3.6	− .3	−.1	.0	.0	.1	Total Av.	3.8	− .4	−.2	−.1	.0	.5	Total Av.	3.8	− .5	−.1	−.2	.2	.4

TABLE IV

DEVIATION OF INDIVIDUAL MEANS FROM MEANS FOR ALL LIST LENGTHS

(3-Syllable Words)

Words at: 1 Second						2 Seconds						3 Seconds					
Mean Gr. Age	Gen. Mean	List Length				Mean Gr. Age	Gen. Mean	List Length				Mean Gr. Age	Gen. Mean	List Length			
		2	4	6	8			2	4	6	8			2	4	6	8
9.1	1.7	− .4	.1	.0		9.0	2.1	− .7	−.7	.0		8.9	1.4	− .5	.0	.0	
10.5	2.0	− .5	.1	.0		10.4	2.3	− .5	−.5	.0		10.0	2.4	− .9	−.4	.0	
11.1	2.7	− .9	−.4	.0		10.8	3.0	−1.2	−.7	.0		10.8	2.6	− .8	−.4	.0	
12.4	3.0	−1.1	−.4	.0		12.1	3.2	−1.3	−.6	.0		12.0	3.1	−1.3	−.4	.0	
Lower Gr. Av.		− .7	−.1	.0		Lower Gr. Av.		− .9	−.6	.0		Lower Gr. Av.		− .9	−.3	.0	
13.4	3.0	−1.1	−.1	−.2	.2	13.5	3.1	−1.0	−.3	−.3	.3	13.5	3.6	−1.6	−.4	−.2	.1
14.2	3.2	−1.2	−.2	−.1	.1	14.1	3.4	−1.5	−.4	−.4	.4	14.1	3.8	−1.8	−.4	.0	.0
15.3	3.5	−1.5	−.4	.1	−.1	15.1	3.4	−1.4	−.3	.0	.0	15.5	3.2	−1.2	−.3	−.1	.1
16.3	3.8	−1.8	−.6	.1	−.1	16.2	3.6	−1.6	−.4	−.4	.4	15.8	4.0	−2.0	−.4	−.1	.1
16.9	4.2	−2.2	−.7	.1	−.1	16.9	4.2	−2.2	−.7	−.1	.1	16.9	4.2	−2.2	−.9	.1	−.1
18.1	4.2	−2.2	−.8	.0	.0	18.1	3.9	−1.9	−.6	−.2	.2	18.1	4.4	−2.4	−.9	−.1	.1
Total Av.	3.1	−1.3	−.4	.0	.0	Total Av.	3.2	−1.3	−.5	−.1	.1	Total Av.	3.3	−1.5	−.4	−.1	.1

TABLE V

DEVIATION OF INDIVIDUAL MEANS FROM MEANS FOR ALL LIST LENGTHS
(All Syllabic Lengths)

Syllabic Length	Rate	List Length					
		2	4	6	8	10	12
1	1″		−.3	−.1	.0	.0	.1
	2″		−.4	−.2	−.1	.0	.5
	3″		−.5	−.1	−.2	.2	.4
2	1″	− .7	.2	.1	−.1		
	2″	− .9	−.2	.0	.0		
	3″	− .8	−.1	.0	.0		
3	1″	−1.3	−.4	.0	.0		
	2″	1.3	−.5	−.1	.1		
	3″	−1.5	−.4	−.1	.1		
4	1″	−1.0	−.2	.0			
	2″	−1.3	−.4	.0			
	3″	−1.1	−.1	.0			

were not considered. This policy was followed in order to eliminate, as nearly as possible, artificially depressing influences from our consideration.

After Means were thus calculated, they were tabulated, together with the individual deviations, for various list lengths at various rates, for one- and three-syllable words, in Tables III and IV. Thus each quantity in these tables, rather than being the Mean for a specific Mean Grade-Age and list length, is the deviation of that Mean from the general Mean for list lengths at that Grade-Age level. Consequently, the quantity .1, under four-word lists for Mean Grade-Age 9.1, when words are given at one-second intervals, signifies that, for all third graders, with a Mean Age of 9.1 years, the Mean number of words reproduced at this age, for four-word lists was larger by .1 of a word, than the general Mean, regardless of the length of list. Thus should each quantity be interpreted, plus deviations showing that the specific average is larger than the general and minus quantities denoting a smaller specific average than the general.

Table V is a summarizing table including the Average Deviation for all list lengths presented, when length is held

constant and age of subjects is allowed to vary, for one-, two-, three-, and four-syllable words. List lengths are distributed horizontally, syllabic length and rates vertically. Reading of the Table seems self-explanatory.

Now, let us turn to an examination of these tables, relative to the tendencies which they reveal.

1. The first fact to be pointed out is the confirmation given by these tables to the observation made, by inspection of Tables I and II, that two- and four-word lists are too short to measure satisfactorily the word span. In 85 cases out of 90 in which deviations are recorded for specific Means, from the general, for two- and for four-word lists, the deviation is negative and consistently increasing in negative extent, with the age of the subjects employed. In four out of the five cases in which a positive deviation is recorded, these deviations are either at the third-grade or fourth-grade levels, and for four-word lists, which would show that, for the lowest grades, four words come nearer to measuring the word span than at any higher level. But two-word lists and four-word lists are unquestionably too short. And an examination of Summarizing Table V shows the same relationship for two-syllable and for four-syllable words.

2. When two- and four-word lists are eliminated from further consideration by the above observation, we quickly see (Total averages of Tables III and IV, Summarized in Table V) that large Average Deviations are mostly eliminated, for only 5 out of 27 deviations are larger than .1 of a word. Further we observe that consistency of deviation has disappeared, with a few exceptions, and numerous positive and negative deviations appear in the same series, as we hold list length constant and vary the age. And this same observation is also true of the Average Deviations for entire age series. This would not be as significant as it is, were it not for the fact that each individual Mean is derived from a fairly large population. (See Tables I and II, where populations are shown to vary from 13 to 114 with an average of 64.7 cases.) But since the population is fairly stable, it seems that, for lists above four words in length the Mean number of words reproduced must

remain largely unaffected by length of list presented. Thus, individually derived Means must only vary slightly about the true curve of Means for specific types of words presented with reference to index of organismic development. In other words, it seems that the number of words of a specific type that an individual can reproduce is a function of development in the individual, alone, and not influenced by excessive length of lists presented.

3. There are, however, a few exceptions to the above observations which must be explained before any definite general conclusion can be justified. For example, Table III reveals a consistent positive deviation of .1, .5, and .4 of a word for twelve-word lists of one-syllable words, at one second, two-second, and three-second intervals, respectively. This would seem to indicate that twelve-word lists are better reproduced than others. But there are a number of arguments to show that this does not necessarily follow.

(*a*) The increase from interval to interval is not consistent as are the increases in the average of the general Means. In Table III, we see that the average general Means run with increase of interval, as follows: 3.6, 3.8, and 3.8. Average Deviation varies .1, .5, and .4. Though this is not in any way conclusive evidence, it points in another direction from mere acceptance of the superiority of twelve-word lists.

(*b*) We have already referred to the differential associability, from word list to word list, which was not successfully controlled in this experiment. A bit of examination will bring its nature more clearly to light.

We find, in Table III, for ten-word lists at one second, that the Lower-Grade Average Deviation is .2, while the Average Deviation for both Lower and Higher is .0. Here we must conclude that the Lower-Grade ten-word lists were much more associable than the Higher-Grade lists, comparatively, and also much more associable, than the remainder of the word lists of the Lower-Grades, while the Higher-Grade lists were of greater difficulty than other Higher-Grade lists. Consequently, an average of the two influences resulted in apparently ordinary difficulty (.0 of a word). For the six-word lists, also, at the same rate, Lower-Grade lists showed an Average Deviation of − .2 words while the total Average Deviation was but − .1. Here there is the reverse condition of a difficulty in Lower-Grade lists and easier Higher-Grade lists, resulting in the low deviation, generally.

Now, if we were to group, by accident, a number of easy lists, the scores would necessarily be abnormally high. Or if we grouped a number of unusually difficult series at some point, we would have a sporadic, excessive, negative deviation. Though the former condition cannot be objectively demonstrated to be present, the latter is very definitely so, in Table III, for words at two seconds, in the six-word list. Here, in Lower Grades, there is a difficulty which manifests itself in a deviation of .0 (actually − .03). In the Higher Grades, this difficulty is increased so that the total Average Deviation is − .2 (− .22) words. Now, for an example of the former condition—

one where comparatively easy lists are grouped—we might very well point out twelve-word lists at one, two, and three seconds (Table III). It might therefore be that apparent superiority of twelve-word lists is only the result of a grouping of easier lists.

(*c*) We are further inclined to accept the argument set forth in (*b*) just above, when we note that the apparent superiority of the twelve-word lists is not supported by a gradual increase in superiority for eight- and ten-word lists. A check of Table III bears this out, except at the three-second interval, where greater superiority of ten-words must altogether be explained by the great ease of the Lower Grade ten-word list, resulting in an Average Deviation of .4.

Consequently we are convinced that the apparent superiority of twelve-word lists is a false appearance, due to an unfortunate grouping of lists with large Coefficients of Associability, resulting in larger Means, in the three cases pointed out.

In proving this statement we have also pointed out the source of all other exceptions to the generalization which suggests itself and must therefore conclude:

1. That four-word lists of any type are too short, perceptibly, throughout the age-range studied, to be used to measure the ability to reproduce disconnected word lists.

2. That six-word lists must also, though perhaps imperceptibly, limit the measure of this ability, at least under certain conditions.

3. That there is a span for reproduction of disconnected word lists which is independent of the number of words presented.

4. That this span is not influenced by excessive list length presented in a manner sufficient to be detected by the techniques of this experimental series.

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PALMAR SKIN-RESISTANCE CHANGES CONTRASTED WITH NON-PALMAR CHANGES, AND RATE OF INSENSIBLE WEIGHT LOSS [1]

BY CHESTER W. DARROW AND G. L. FREEMAN

That the resistance of the skin of the palms has a significance different from that in other areas has been definitely supported by the work of Richter. He believes (1) the resistance of the palms of the hands to be controlled by the thermoregulatory activity of the sweat glands under the influence of somatic and sympathetic nerves, while the resistance of the backs of the hands, and of the rest of the body, in general, is controlled by the thermoregulatory 'insensible perspiration' of the epithelial cells, 'largely, if not entirely free from nervous control.' [2] Variations in the palmar resistance are 'associated with changes in the central nervous system,' while those in the backs of the hands are associated with 'the amount of heat liberated by the muscles under varying degrees of tension.' Although we agree with many of Richter's observations, this paper offers evidence in line with certain other interpretations.

In the first place, one of the present writers (3) has shown that resistance changes in the backs of the hands are, at least in many instances, associated with eruptions of sweat. In form, magnitude, and latency after stimulation, these are often indistinguishable from those on the palms. Furthermore, it has been pointed out (4–5) that the probable function of perspiration on the palms (and also on the soles of the feet) is primarily the maintenance of the pliability and adhesiveness

[1] Studies from the Behavior Research Fund and the Institute for Juvenile Research, Series B, No. 201, and from the Department of Psychology of Northwestern University.

[2] In a later article (1929)[2] Richter states that "the dorsum also contains sweat glands, although in less abundance than the palmar areas. Their effect *on resistance*, whatever it is, must be masked, therefore, by that of some other component of the skin." (Italicized words ours.)

essential to cutaneous sensory acuity and good grip upon objects. The common practice of moistening the hands when manipulating objects is testimony to the importance of this function. Kuno's finding (**5**) that sweating of the palms and soles is characteristic of situations involving 'mental stress' while sweating elsewhere on the body is specific for conditions involving increase in temperature is logical basis for such a view. Katz (**6**) has shown experimentally the importance of moisture in tactual discrimination. And not least in importance the dry palm common in sleep [3] even when the other body surfaces are warm and moist, calls for an explanation other than the assumption that the palmar sweat glands are primarily for temperature control. If we grant, however, the importance of palmar perspiration for various manipulative functions, the secretory and electrical changes in the palms acquire a significance for sleep as well as for psychological phenomena of the waking state which they lack if they are related solely to mechanisms of temperature control. In this paper we shall present evidence that large galvanic reactions occur in the palms in conditions involving aroused 'conscious' activity, and that this is not equally true of other skin areas examined.

In a study carried on by the writers to determine the relation of electrical skin resistance to total insensible weight loss (**8**) the differences in the reaction of different skin areas to different types of stimuli became apparent. The readings of skin resistances in the palms and in other body surfaces were made in conjunction with minute by minute observations on the total insensible weight for periods of from one to two hours on thirteen subjects. Total insensible weight loss, as shown by Benedict and Root (**9**) and by Wiley and Newburgh (**10**),

[3] Instances of failure to demonstrate high palmar resistance during sleep are probably due (1) to application of electrodes elsewhere than on the palms, (2) to use of excessive current through the subject as may happen with the conventional bridge when a subject starts at low resistance, (3) to use of alternating current, (4) to comparison of 'sleeping' resistance with resistances immediately preceding and following sleep. Evidence would indicate that high resistance is not specific for 'loss of consciosness' but for some general physiological condition predisposing toward sleep. Miles offers evidence that even in sleep perspiration (location not determined) may increase as one attains a progressively more rested condition.

provides an index of the rate of the general metabolic activity of the body.

The apparatus and general procedure are described elsewhere (**8**). It will suffice to state that the galvanic skin reflex measurements were made by means of a Behavior Research Resistance Box with a commutator for serially switching in first one active electrode plus an appropriate compensating resistance, then another electrode plus its compensating resistance (**11**). The skin was pricked underneath the 'indifferent' electrodes to eliminate the greater part of the contribution to total resistance which otherwise would be made by that area of contact. The weight loss determinations were made by the Benedict modification of the Sauter balance (**9**) with an electro-hydraulic arrangement added for automatically maintaining the scales in approximate equilibrium, thus permitting readings of the subject's weight change minute by minute.

The data for the present study are the various parallel measurements of resistance and of weight loss which accompanied a clear-cut indication of change in any one of the areas to which our active electrodes were attached. For example, if we were recording resistances of the right palm, the right wrist, and the left leg along with the rate of total insensible weight loss of the body, and if the left leg showed a clear-cut resistance change after an electric shock, then the data on change in resistance of the three areas and change in general rate of weight loss will be presented. On the other hand, if none of the several simultaneous measures of resistance showed a large clear-cut change after stimulation, the data will not be presented. This method of selection of our data seems necessary in the present paper to avoid encumbering the report with material having no bearing on the question under consideration.

To determine the relative significance of palmar and other skin resistance changes we present in Table I the following data on each of the reactions which was selected according to the foregoing criterion: (1) The resistance of the palmar and non-palmar skin areas before and after stimulation, (2) the

rate of insensible weight loss before and after the initiation of the activity, (3) the nature of the subject's activity associated with the change. Naturally any description of the subject's probable activity is difficult, and any attempt that we make to classify it will meet with criticism. We have, nevertheless, given very general designations to the activities implied by the various situations in which reactions occurred. Whatever terminology the reader may apply, we believe that a psychologically significant difference will be recognized between the groups of situations we shall indicate.

In Table I the changes manifested by the palmar areas are compared with the largest simultaneous change manifested by any of the recorded non-palmar areas. The difference between the conductance changes in the two areas will be used as an index of the degree to which palmar or non-palmar areas predominate in the response. Of course, the non-palmar areas will not be strictly comparable from subject to subject owing to the fact that our work was largely exploratory, and the same areas are not always represented, nevertheless the consistency of tendency shown by even the varied areas in comparison with the palm amply demonstrates the point here at issue.

The values of the resistances and of the resistance changes in the various areas will be compared in Table I only after resistances have been translated into the reciprocal value known as conductance. The *micromho* [4] is the unit of conductance which will be employed. This translation of resistance values into conductances before making comparisons appears to be required by the fact that recent work (**12**) has shown that the amount of perspiration tends to vary as the reciprocal of the resistance change in corresponding areas. Conductance change of the palm minus the largest recorded simultaneous non-palmar conductance change gives us an index of the degree of palmar dominance in any reaction. The degree of palmar dominance is used as a basis for ranking the reactions presented in Table I. The greater the conductance change in the palms compared with the maximum observed change

[4] The reciprocal of the megohmic resistance.

elsewhere, the nearer the top of the table the particular reactions are listed. An examination of Table I indicates, as we progress from top where palmar reactivity predominates, towards the bottom where it is quite obscured, a rather definite change in the general type of activity involved. At the top where the palmar changes are the larger, the 'attention,' 'perceptual,' and 'alertness' functions (designated by asterisks) predominate, while at the bottom of the table where non-palmar changes are largest, 'muscular activity' (marked by a dagger †) is most frequent. There is a slight suggestion that general metabolic activity, as indicated by rate of insensible weight loss, is greatest toward the bottom of the table. A series of activities (indicated by circles o) which have been generally classed as 'mental work' appear scattered throughout the table. The evidence on the whole appears consistent with the hypothesis that the palmar reactivity is peculiarly a function of the higher mental activities involving 'attention,' or 'alertness' while the non-palmar areas are primarily thermoregulatory in function.

There appears a possible alternative to this view, namely, that these different skin areas represent merely differences in the ease of excitation. One of the writers has shown such a difference in records of simultaneous reactions of the palms and backs of the hands.(**3**) It was shown that under repeated stimulation the palm may become reactive before the back has begun to respond, and that, as the general level of total bodily excitation becomes greater and the palmar resistance drops toward a physiological limit of reactivity, the back may become increasingly responsive to stimulation and may ultimately far surpass in magnitude the reactions of the palm. That a difference in the ease of excitation is not the only factor determining the differences here observed is shown by the fact that low palmar resistances are not selectively collected toward the bottom of Table I as would be true if palmar reactivity had become less because of approach toward its physiological limit due to stimulation. Nor do the non-palmar resistances appear very markedly lower toward the bottom of the table. The general level of metabolic activity indicated by rate of

TABLE I

Subject	Stimulus	Probable Activity	Palm			Back of Hand			R. Leg, R. Arm or R. Wrist			L. Leg or R. Wrist			Weight Loss		Rank Order
			Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Grams per Minute before Reaction	Change in Rate During Reaction	Conductance Change in Palms Minus Highest Non-Palm Change
Br	None	Anticipation*	12.0	83.4	52.4	12.5	80.0	7.0	^{A}19.0	52.6	6.2				0.5	0.2	45.4
Bo	Warning	Anticipation*	15.0	66.6	43.4				^{L}65.0		0	^{L}62.0	16.1	0.3	0.5	0	43.1
Co	Word ass'n	Mental work, embarrasment°	19.0	52.6	36.4	23.0		0							0.56	−0.06	36.4
Da	Slight shock	Awakens from sleep startle*	36.0	27.6	49.1	16.0	62.5	14.4							0.4	0.2	34.7
Co	Addition	Mental work°	25.0	40.0	37.0	24.0	41.7	5.9							0.15	0.05	31.1
Vi	None	Awakens from sleep*	67.0	14.9	28.6				^{W}36.0	27.8	1.6	^{L}32.0	31.2	−1.8	0.2	0.1	27.0
Bo	Drop pencil	Awakens, anticipation*	20.0	50.0	21.4				^{L}64.0		0	^{L}65.0		0	0.4	0.1	21.4
Da	None	Reports anticipation*	36.0	27.6	26.0	17.0	61.2	6.3							0.1	0	19.7
Fr	Warning	Anticipation*	45.0	22.2	16.2				^{L}22.0		0	^{L}23.0		0	—	—	16.2
Eb	Personal questions	Mental work, embarrasment°	18.0	55.5	15.9	17.0		0							0.3	0.2	15.9
Wo	None	Awakens from sleep *	24.0	41.6	13.9	47.0	21.3	0.9							—	—	13.0
Vi	Increase shock	Muscular activity†	27.0	37.0	13.0				^{W}37.0		0	32.0		0	0.5	0.1	13.0
Eb	Addition	Mental work°	38.0	26.3	12.7	16.0		0							0.1	0.1	12.7
Wo	Light shock	Awakens from sleep —startle*	33.0	30.0	13.5	47.0	21.3	0.9							0.4	0	12.6
Bn	Warning	Anticipation*	11.5	87.0	13.0				^{A}43.0	23.2	0.6	72.5	13.8	1.0	0.5	0.05	12.0
Bn	Voluntary? movement	Muscular activity†	12.0	83.2	12.0				^{A}44.5	22.4	0.8	^{W}76.0	13.2	0.4	0.3	0.3	11.2

TABLE I—*Continued*

TABLE I—*Continued*

Subject	Stimulus	Probable Activity	Palm			Back of Hand			R. Leg, R. Arm or R. Wrist			L. Leg or R. Wrist			Weight Loss		Rank Order
			Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Resistances in 1000 Ohms before Reaction	Conductances in Micromhos before Reaction	Conductance Change During Reaction	Grams per Minute before Reaction	Change in Rate During Reaction	Conductance Change in Palms Minus Highest Non-Palm Change
Fr	Interruption at door	Attention apprehension*	39.5	25.3	8.0				^{L}20.0	50.0	−2.5				0.5	0.5	10.5
Wo	?	Awakens from sleep*	32.0	31.2	5.8	47.0		0							—	—	5.8
Bo	Increase shocks	Muscular activity†	12.0	83.3	8.3				^{L}65.0	15.3	0.8	^{L}61.0	16.4	3.6	0.5	0.3	4.7
Co	Pulls dynamometer.	Muscular activity—tension†	15.0	66.7	8.0	25.0	40.0	3.5							0.45	0.15	4.5
Eb	Dynamometer and shock	Muscular activity†	13.0	76.9	7.0	14.0	71.4	5.5							—	—	1.5
Cr	Weak shock	Muscular activity†	77.0	13.0	2.4				^{L}76.0	13.2	0.7	^{W}60.0	16.7	0.2	1.0	0.2	1.4
Eb	Pulls dynomometer.	Muscular activity†	14.0	71.4	5.5	15.0	66.7	4.7							—	—	0.8
Ke	Shock increase	Muscular activity†	55.0	18.3	0.4				^{W}48.0	21.4	0.3	^{L}66.0	15.3	0.8	0.4	0.2	−0.4
Bn	Shocks	Muscular activity†	10.0	100.0	11.1				^{A}40.0	25.0	2.4	^{W}64.5	15.5	14.3	0.5	0.3	−3.2
Fn	Begin shock	Muscular activity†	23.0	43.4	19.1	22.0	45.4	26.1	^{R}30.0	33.3	10.1				0.8	0.1	−7.0
Fn	Increase shock	Muscular activity†	14.5	69.0	14.3	15.0	66.7	24.3	^{A}25.0	40.0	10.0				1.1	0.3	−10.0
Br	Adding	Mental work, recovery from anticipation°	12.5	80.0	−4.6	12.2	82.0	1.4	^{A}19.0	52.6	5.5				0.5	0.2	−10.1
Fr	Shock	Muscular activity†	26.0	38.4	−2.7				^{L}22.0	45.4	10.1	^{L}23.0	43.4	6.6	1.1	0.2	−12.8
Hi	Word ass'n	Mental work, embarrasment°	18.0	55.5	11.2	24.0	41.6	20.9							1.2	0	−19.7
Hi	Tapping	Muscular activity†	19.0	52.6	14.1	39.0	25.6	35.9							0.7	0.7	−21.8
Br	Increase to rapid adding	Muscular activity mental work°	12.5	80.0	−8.6	15.0	66.7	24.3	^{A}17.0		0				0.6	0.1	−32.9

* Alertness, etc. † muscular activity ° mental work

weight loss is, however, often greater toward the bottom, as would be expected due to the concentration there of instances of definite muscular activity.

The fairly clear-cut differentiation of the effects of 'alertness' from those of 'muscular activity' is further shown by the fact that the average 'palmar dominance' of the twelve 'alertness' items marked by the asterisk is 21.7 ± 8.4 and the average of the thirteen 'muscular activity' items marked with the dagger is -1.4 ± 6.3. This gives a difference of 23.1 ± 10.4 between averages for the two conditions. Although the difference is only 2.2 times the P.E. of the difference the small amount of overlapping of the two sets of measures is reason for believing it significant.

Whether the distribution of the 'mental work' items throughout the entire range of the table is an indication that at one end of the table mental work was characterized by little muscular activity, and at the other end by a great deal of activity is open to speculation. The wide range of variation in tension during mental work that has been shown by one of the writers (**13**) to characterize different individuals and various types of mental activity suggests this possibility. It further suggests the importance of determining if the degree of non-palmar dominance will serve as an index of the amount of tension in mental work.

The reactions of the palm which, according to the hypothesis previously set forth, serve in preparing the organism for various forms of manipulative activity, and which seem here to be an index of the arousal of the organism to a state of anticipation or alertness apparently may also be exaggerated and extended in chronic anxiety, into a condition of persistant low palmar resistance. Solomon and Fentress (**14**) found generally low palmar resistance in instances of what was clinically designated as 'free anxiety' in cases of chronic anxiety neurosis, while in conditions where anxiety was relieved or avoided through 'conversion symptoms' they found high palmar resistances. A somewhat similar relation of 'free anxiety' to palmar resistance was also found by Darrow and Solomon (**15**), working with psychotic patients. Resist-

ances of the backs of the hands did not appear related to the ratings on clinical anxiety.

That resistance changes on the back of the hand should be greatest in muscular activity is, of course, to be expected if perspiration in non-palmar, non-plantar regions is primarily for temperature control. The results here are in keeping with Richter's conclusion that changes in the dorsum of the hand are symptomatic of variations in muscular tension, muscular tension being recognized as a primary factor in metabolic rate. In agreement with this he found high back resistance in conditions of psychopathological passivity. The exceptional instances in the study by White (**16**) in which voluntary muscular tension was not accompanied by reduced resistance are possibly attributable to the fact that his records were from the palms.[5] The finding of Kuno and Ikeuchi (**17**) that increasing atmospheric temperature caused increased non-palmar, nonplantar sweating while there was no increase in perspiration on the palms is further evidence that perspiration in palmar-plantar regions is only incidentally of significance in temperature control.

Summary and Conclusions.—Evidence has been presented that the relative magnitude of galvanic reactions in palmar and in non-palmar areas is determined by the type of activity giving rise to the change. It is shown that situations favoring an increase in the subject's anticipation, alertness, or apprehension (including arousal from sleep), are likely to be attended by marked increase in conductance of the palm, while situations involving various sorts of muscular activity are likely to be attended by large increases in the conductance of non-palmar areas. Activities designated roughly as mental work may effect marked changes in either type of reacting mechanism, the locus of greatest activity possibly depending upon the amount of muscular activity involved.

These observations have been shown to be in agreement with certain findings of other investigators. They further have been shown to be consistent with the view that while perspiration on non-palmar, non-plantar areas is thermo-

[5] When recording from one hand he does not state if both electrodes were on the palm.

regulatory in function, that on the palms and soles is primarily to maintain the adhesiveness and pliability essential to tactual acuity and good grip upon objects, and is psychologically significant because it is normally called forth in situations demanding alertness in the mobilization of the energies of the organism for emergency adjustive response.

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STUDIES IN CROSS EDUCATION

III. Kinæsthetic Learning of an Irregular Pattern

BY T. W. COOK

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The large amount of transfer to a hand or foot tested after practice with another hand or foot makes the avenue of such transfer a problem of some importance. The aim of the experiment reported below was to vary the conditions of learning in ways that, from previous research, seemed likely to aid in finding some of the factors in this transfer of learning from one muscle group to another.

In the first two of the writer's studies of cross-education the subjects were asked to trace a path through a star-shaped maze seen in a mirror. Transfer of learning in mirror-tracing, however, permits an all too facile explanation in terms of a crude form of the 'identical elements' theory.[1] Vision and the eye-movements of vision play a part in guiding most bodily movements, and the transfer from one hand or foot to another hand or foot might be due to the aid given by the sense of sight during the learning and afterwards in the transfer tests. A step in analysis of the nature of transfer, therefore, is an experiment in non-visual learning. If subjects, blindfolded throughout the learning and transfer tests, show improvement in the latter, it is unlikely that the dual role of vision is the sole cause of the transfer found in earlier investigations of cross-education. Particularly if the amount of transfer is the same whether the subject can or cannot see the pattern, progress toward understanding the nature of transfer should come from study of factors common to visual and non-visual learning.

A top view of the maze used in the present experiment is shown in Fig. 1. This maze has two novel features, the

[1] This statement applies to all previous experiments on cross-education.

peculiar winding course of the path and the absence of blind alleys. The latter were omitted in order to simplify the subject's task. Individual differences in speed of maze learning and the desirability of testing transfer from each hand or foot to the other three limbs, called for a large number of subjects, and enough volunteers could not be obtained if the experimental sessions took much time.

The shape of the pattern was outlined after an orientation

FIG. 1. Irregular maze.

experiment using a regular maze pattern with the traditional blind alleys. Introspective reports of the four subjects in this experiment brought out the possibility of a highly generalized mode of transfer. A choice such as is called for at a critical point of the usual maze can be verbalized. At each turn the subject can note whether the correct route is right, left, or straight ahead, *memorize the order of the words*, and translate that word order into a succession of choices in subsequent trials with another hand or foot.[2] Although such transfer may be important in understanding the relation of general ideas or percepts to bodily movement, it was desirable to avoid it here. I therefore tried to make the maze pattern so irregular that it could not be verbalized. How far I succeeded the reader may judge by attempting to describe the accompanying pattern in words. The curving path has the added advantage of favoring the formation of a single movement pattern in the act of learning. By noting the degree to

[2] It is not implied that verbalization always occurs in maze learning. I merely desired to avoid the possibility of transfer via words.

which each subject had achieved a smooth, unitary movement in the practice tests I could observe whether the pattern seemed to be learned as a whole, and whether the latter favored or hindered transfer.

The maze path shown in Fig. 1 was drawn on three-ply wood and cut out with a jig-saw. The pieces of wood thus obtained were nailed to blocks three-quarters of an inch thick, and the whole nailed to a solid base 20 inches long by 12 inches wide. The maze path is one-quarter inch wide and its total length is 48 inches. The edges and bottom of the path were painted dull black for convenience in photographing.

The stylus for mirror-tracing the star-shaped maze [3] was altered slightly to suit the requirements of the present experiment. No change was made in the wooden sandals used in tracing with either foot, or the wooden handle of the hand stylus. Since the subjects were now blindfolded, however, the tip of the stylus need not project from the front of the sandal. But the foot required a greater 'clearance' from the top of the maze and the stylus had to be more solidly attached to the sandal than formerly, because the lack of visual aid in adjusting movement to stimulus pattern made a subject more likely to catch the heel of the sandal on the maze, and also to try to overcome an obstruction by 'main strength.' Accordingly one lip of an iron bracket one and one half inches long was bolted to the bottom near the front end of each sandal. On the other lip of the bracket, which projected downwards at right angles to the plane of the sandal, was soldered an one eighth inch brass rod two and one quarter inches long. The tip of the stylus was a half-inch washer soldered to the end of the brass rod. The hand stylus was an one eighth inch brass rod driven into a round wooden handle. One and one half inches from the handle the rod turned at right angles, and ended two inches further in a tip similar to the one just described.

The general position of the stylus in the maze path may be seen in Fig. 3 of the first paper in this series.[3] A cross-section of the path through the maze in the present experiment differs from the star-shaped path only in two details: (1) The width of the path through the upper layer is one half inch in the star-shaped maze and one quarter inch in the present maze. (2) In the latter the intermediate layer is set so far back from the edges of the maze path that limitation of movement in a lateral direction comes wholly from the sides of the path through the upper layer.

For both hand and foot trials the subject was seated on a chair, and the maze so placed that with the subject in 'normal position' (arms at rest at his sides and feet close together) the hand or foot to be tested was at the point indicated by the letter *S* in Fig. 1. The chair for foot tracing had pieces of wood two inches wide bolted to the sides for arm rests, and the chair sat on a platform the same height as the thickness of the maze. The latter was held in position by a frame on the floor in front of the platform, bringing the upper surfaces of maze and platform on the same level. In trials with either hand the maze was fixed on a table at a convenient height. The subject's view of the maze was cut off by means of a black cloth three feet square. Two corners of this cloth were tied round the subject's neck, and the other corners fastened to uprights two feet in front and in the horizontal plane of his eyes. The method proved satisfactory. The subject could not see the maze or the movements of his hands or feet; yet he was free from the unnaturalness of blindfolding.

[3] Cook, T. W., Studies in cross education. I. Mirror tracing the star-shaped maze, *J. Exper. Psychol.*, 1933, **16**, 146–147, Figs. 1, 2, 3.

At the beginning of each experimental period as soon as the subject was seated he was shown the stylus and asked to read a typewritten copy of the following: "You are to trace a path through a maze with the stylus shown you. The general direction of progress is from left to right. The path is winding but there are no blind alleys. You have only to be careful not to turn back and go as fast as you can." He was allowed to study the sheet as long as he wished, and the experimenter then went over the instructions point by point to make certain that no misunderstanding had occurred. The stylus was handed to the subject and the cloth tied around his neck to shut off his view of the maze. Next the maze was uncovered and the hand or foot placed in starting position just inside the entrance to the left end of the path. A ready signal was given before the starting signal. Timing was done with a stop-watch, and all records (as before) are in seconds.

The subjects were 120 male students of Acadia University and Horton Academy, divided according to conditions described later, into twelve groups of ten subjects each. All were right-handed. Each subject was given 20 practice trials with one hand or foot, followed three minutes later by 10 trials with another hand or foot. The intervals between trials with any one hand or foot were made somewhat long in order to lessen the chances of fatigue masking learning. The rest period between a given trial and the next following was determined by the length of the first, and was measured from the starting point of the earlier to the starting point of the later trial. For all but the longest trials the relation between length of trials and interval between trials was as below:

Length of Trial	Time from Beginning of Trial to Beginning of Next Trial
10 seconds or less	30 seconds
11–20 seconds	45 seconds
21–30 seconds	60 seconds

Trials of longer than thirty seconds were succeeded by a rest interval of the same length as the trial just completed. The order of practice and transfer trials for each of the twelve groups is given in Table I. It will be seen that all combinations of hand and foot practice and transfer trials were used.

Table I also contains averages of the time records for each of the twelve groups. One classification of these groups is based on the hand or foot used in the practice trials. Of the 120 subjects, an equal number (30) had practice trials with the right hand, left hand, right foot, and left foot. These four sections were not equated, and it is possible that the comparative value of the data in the four columns on the right of Table I (each column representing the average of 30 subjects for one hand or foot) may be affected by differences in the ability of the several groups. However, two conclusions seem fairly warranted. (1) The practice trials for the right foot and left foot are almost identical. The total time for twenty practice trials is, right foot, 2501 seconds; left

PRACTICE AND TRANSFER TRIALS FOR 12 GROUPS. TIME IN SECONDS

Group	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average of Three Groups

PRACTICE AND TRANSFER TRIALS FOR 12 GROUPS. TIME IN SECONDS

Group	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average of Three Groups			
Practice																
Trials	Right Hand			Left Foot			Left Hand			Right Foot			R.H.	L.H.	R.F.	L.F.
1	18.0	15.1	14.5	47.6	31.1	27.6	35.6	33.2	40.5	28.2	35.0	34.5	15.9	37.7	32.6	35.4
2	10.9	11.1	10.6	23.9	17.1	15.7	13.2	12.3	13.2	25.5	22.1	23.0	10.9	12.6	23.5	18.9
3	8.2	9.7	8.8	15.7	18.2	18.2	10.3	10.4	10.9	19.1	18.1	15.1	8.9	10.5	17.5	17.3
4	7.5	8.7	8.1	15.4	13.2	14.4	7.7	7.7	8.9	13.9	18.0	16.8	8.1	8.1	16.2	15.3
5	7.3	8.0	8.3	13.3	21.2	14.9	8.2	8.7	7.7	17.6	15.3	12.2	7.9	8.2	15.0	16.4
6	6.9	7.6	7.8	14.6	10.2	13.2	8.4	6.3	7.6	13.5	13.3	10.9	7.4	7.5	12.6	12.7
7	6.8	8.6	7.8	18.2	9.8	10.2	7.2	7.1	7.0	12.7	15.1	12.8	7.7	7.1	13.6	12.7
8	6.7	7.3	7.1	10.4	11.9	10.8	7.7	7.6	7.0	12.0	12.0	11.5	7.1	7.5	11.8	11.0
9	6.2	7.3	7.1	9.7	11.3	9.6	6.1	6.4	7.9	9.6	10.6	10.5	6.9	6.8	10.2	10.2
10	6.5	7.1	7.2	9.7	10.9	9.4	6.6	6.1	6.8	7.4	10.5	10.6	6.9	6.5	9.5	10.0
11	6.8	7.1	6.8	11.2	9.4	8.5	7.2	6.2	6.0	8.4	10.7	9.3	6.9	6.5	9.5	9.7
12	6.6	6.5	6.7	8.2	9.7	10.8	6.2	6.0	6.0	7.2	10.8	8.8	6.6	6.1	9.0	9.6
13	7.0	6.4	6.7	8.2	9.7	10.4	6.9	5.6	6.9	9.3	9.5	11.2	6.7	6.5	10.0	9.4
14	6.7	7.3	6.6	9.7	9.0	8.7	6.1	5.7	6.1	7.0	9.7	9.7	6.9	6.0	8.8	9.1
15	6.0	6.5	6.5	12.0	8.0	8.8	6.2	5.6	5.6	9.8	8.2	9.6	6.3	5.8	9.2	9.6
16	6.4	5.9	6.4	9.7	8.7	9.8	5.6	5.5	5.7	7.2	9.3	8.9	6.3	5.7	8.5	9.4
17	6.1	6.4	6.4	8.4	7.3	9.0	5.5	5.3	5.9	7.4	10.0	7.8	6.3	5.6	8.4	8.2
18	6.3	6.5	6.3	8.2	7.4	8.6	5.2	5.9	5.5	8.1	7.7	8.5	6.4	5.5	8.1	8.1
19	5.7	6.3	6.4	8.0	8.9	9.3	5.4	5.7	5.4	7.0	8.5	9.5	6.1	5.5	8.3	8.7
20	5.9	6.6	6.1	8.4	7.8	8.1	5.2	5.6	5.4	8.3	7.8	7.2	6.2	5.4	7.8	8.1
Transfer																
1	L.H.	R.F.	L.F.	R.F.	L.H.	R.H.	R.H.	L.F.	R.F.	L.F.	R.H.	L.H.				
1	7.5	11.4	17.7	11.6	7.9	9.8	6.5	16.0	19.6	11.5	8.6	14.2	8.3	9.9	14.2	15.1
2	7.0	9.7	11.3	7.4	5.5	8.1	6.3	13.8	10.2	10.2	8.1	7.0	7.5	6.8	9.1	11.8
3	6.5	8.1	9.7	9.0	7.4	8.0	6.7	10.3	9.4	10.0	7.4	6.8	7.4	6.9	8.8	10.0
4	6.1	7.9	10.8	7.8	6.5	8.0	5.8	12.5	14.9	11.1	6.7	7.6	6.8	6.7	10.2	11.5
5	6.8	7.7	9.5	7.1	5.9	7.3	6.0	8.4	8.9	9.3	6.3	7.5	6.5	6.8	7.9	9.0
6	6.0	8.3	10.1	6.9	5.7	6.8	7.8	8.2	9.5	9.8	6.2	7.8	6.9	6.5	8.2	9.3
7	6.9	8.4	10.2	6.3	5.5	7.4	5.4	9.5	10.5	8.4	6.3	6.7	6.4	6.3	8.4	9.4
8	7.3	8.2	9.7	6.7	5.7	6.7	5.4	8.8	8.1	7.8	6.3	6.8	6.1	6.6	7.7	8.8
9	6.1	7.2	9.3	7.4	5.4	6.1	6.0	7.7	7.5	9.4	5.7	8.3	5.9	6.6	7.4	8.5
10	5.7	8.0	8.5	6.6	5.4	6.1	5.3	8.4	9.7	8.3	6.6	6.2	6.0	5.7	8.1	8.4

foot, 2498 seconds. (2) During the first ten practice trials the right hand is much more efficient than either foot. The absolute difference between right hand and right or left foot is most marked on the first trial. The average time for the first trial is 15.8 seconds with the right hand, 32.4 seconds with the right foot, and 35.0 seconds with the left foot. For the last ten practice trials the differences between right hand and either foot are only slightly greater than the hand-foot differences of about two seconds found in practice and transfer trials in tracing the star-shaped maze with and without the mirror.[4]

The most curious and unexpected outcome is the lack of consistent resemblance between the results of the practice trials with the left hand and the corresponding data for right hand or either foot. The left hand has about the same speed as the left foot or right foot on Trial 1, but approximates the results of the right hand on the second and all later practice trials.

Is there anything in the experimental setting or the behavior and introspections of the subjects that might aid in interpreting the great superiority of right hand over all three other limbs in the first practice trial, and of hands over feet in the nine succeeding trials? We note three things. (1) Within the range of speed for each of the four limbs on the first practice trial (R.H., 6.2—28.0; L.H., 7.2—202.0; R.F., 6.0—100.0; L.F., 11.2—119.0) there is considerable overlapping of the distributions. The number of subjects whose time of the first trial fall between 1 to 10 seconds, 11 to 20 seconds, etc., is given below:

In all four groups there are some individuals who can trace the maze rapidly and with little difficulty on the first trial. In all four the mode is between 11 and 20 seconds. The decided skew toward the higher values in the last three would point to a specific source of difficulty affecting some subjects trained with left hand, right foot, and left foot, and not affecting subjects practicing with the right hand. (2) A few subjects after seemingly acquiring a mastery of the maze pattern,

[4] Cook, T. W., Studies in cross education. II. Further experiments in mirror tracing the star-shaped maze, *J. Exper. Psychol.*, 1933, **16**, 679–700. See also page 150 of article indicated in note 3.

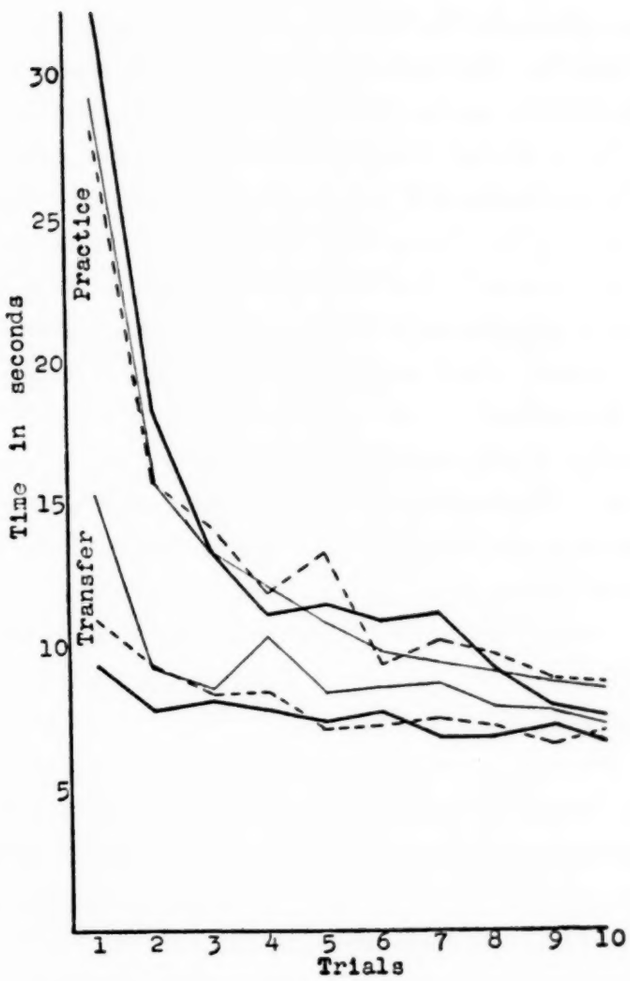

FIG. 2. The effect of the relative location of practice and transfer muscle groups on amount of transfer. Light lines, transfer trials with hand or foot opposite and non-symmetrical to practiced; dotted lines, transfer to same side as practiced; heavy lines, transfer to muscle group opposite and symmetrical to practiced hand or foot.

Time on First Trial	Number of Subjects			
	R.H.	L.H.	R.F.	L.F.
6–10 seconds	6	2	1	0
11–20 seconds	16	13	11	12
21–30 seconds	7	3	7	7
31–40 seconds	1	4	2	4
41–50 seconds		3	3	2
51–60 seconds		1	3	1
Above 60 seconds		4	3	4

became bewildered in some later trial. The preponderance of these 'reversals' in foot trials was striking. There were 6 with the right hand, 9 with the left hand, 26 with the right

foot, and 33 with the left foot. (3) There proved to be three difficult turns in the maze pattern, indicated in Fig. 1 by arrows. Subjects sometimes pushed the stylus against the side of the path at one of these points over and over again, or turned back and retraced part of the pattern. Occasionally a subject persistently jammed the stylus against the top or bottom of the maze. A trend of this sort, when it appeared (as sometimes happened) for the first time near the end of a series of practice or transfer trials, tended to obscure the learning or transfer.

Apparently the irregularity of the pattern is one key to our problem. The shift from a broad, sweeping curve to a short, relatively sudden turn offers little difficulty to the preferred hand even during the exploratory movements of the first trial. For the other three limbs the transition from abrupt to gradual and gradual to abrupt change of direction greatly complicates their task. The non-preferred hand needs only one trial to approach the performance of the preferred hand, but ten trials are required before the feet reach the speed (relative to the hand) that they have with visual aid. According to this hypothesis, the skewed distribution of the first practice trial records for left hand, right foot, and left foot would be due to the fact that with so few irregularities of pattern some subjects find their way around the difficult corners by chance. A glance at the pattern will show that in blind trying around the stylus would sometimes strike the right direction. On the other hand, striking a corner at one of the sharper turns caused a disturbance seemingly out of proportion to the difficulty of the adjustment.

From the standpoint of past experience, one might suspect that the previous training of the right hand in skilled movements consists in part of practice in flexibility. The right hand might be better trained in letting the external situation guide the movements—in a readiness and ability to adjust rapidly to sudden changes in the stimulating situation. For example, it is theoretically possible to trace the maze in Fig. 1 by following one side of the path. As a matter of fact, no subject ever used this method. But in the first few trials

the more adaptable subjects moved cautiously and allowed the limits of the path to guide their movements. Also, there is no doubt that one of the difficulties in initial attempts at tracing with the foot was a tendency to hold the muscles tense and use force rather than finesse. In early trials flexibility and objectivity were a distinct asset.

In successive trials two lines of progress are possible. (1) Subjects may improve in ability to let the external situation guide their movements. They may learn to relax all muscles except those necessary to move the hand or foot, and pay more and more careful attention to external stimuli from the sides of the maze path. (2) Instead of paying closer heed, the subjects may grow more independent of the sensory data resulting from contact with the maze. According to this hypothesis, learning to trace the maze is largely the formation of a unitary (kinæsthetic?) pattern.

The two kinds of improvement serve different trends, the first toward accuracy, the second toward speed. They are not wholly incompatible, for speed depends upon the internal pattern being a fairly accurate copy of the external, and improvement in accuracy must be effected by the 'sensory consequences' of previous trials: *i.e.*, hitting or not hitting the sides of the maze path.

Except for a few subjects in early trials, behavior and introspective data indicate that the learning is almost wholly of the second type. Most subjects tried to drive their way through the maze on the first trial, and under the urge for speed even cautious subjects seemed to depend less and less upon external control by the sides of the maze and more and more upon guidance from previous learning.

If the feet are not improving in adaptability, the large number of 'reversals' in later trials is not surprising. Striking a corner at one of the sharper turns or pressing hard against the top or bottom of the maze tended to break the rhythm of movement. A resulting reversion to the initial stage of dependence on the external stimuli would explain the fact that after such a mishap (usually in foot tracing) the subject often fell into blind wandering, and did not regain his orientation

until a later trial. Even after he had attained such a mastery of the pattern that he had been able to trace the maze at high speed in each of several successive trials, a trial could be seriously disturbed by hitting the stylus against one of the turns in a side of the path with sufficient force to bring the foot to a halt.

The results of Koffka and Wolf [5] also indicate that unusual features of a pattern diminish or become more exaggerated on successive reproductions. Since our maze has three points at which there is a relatively abrupt turn in the path, it is possible that the relative values of abrupt and gradual curves changed on each trial (unless checked up by hitting the side of the path) and hindered the development of an internal pattern accurately copying the external.

A comparison of the amount of transfer in the present and former experiments of the author may be obtained from Table I and corresponding data in the two earlier papers of this series.[3,4] In Table I the first twelve columns give averages of practice and transfer trials for each group. Although a reliable estimate of the amount of transfer cannot be obtained without combining the records of several groups (in view of the fact that there were only ten subjects per group), it is significant that *with every group* there is evidence of a considerable degree of transfer.

The four columns on the right of Table I represent averages from thirty subjects. The practice trials for the right hand were taken with Groups I, II, III; left hand, Groups VII, VIII, IX; right foot, Groups X, XI, XII; left foot, Groups IV, V, VI. The transfer data for the right hand are averages from Groups VI, VII, XI; left hand, Groups I, V, XII; right foot, Groups II, IV, IX; left foot, Groups III, VIII, X. Each set of practice trials is paired with transfer trials taken with three *other* groups, but the number of subjects (30) ensures a much greater reliability than could be expected from a comparison of single groups. The above method of combining the group results allows us to estimate the relative amount of transfer to right hand, left hand, right foot, and

[5] Köhler, W., *Gestalt Psychology*, p. 310.

left foot. Averaging all right hand, all left hand, all right foot, and all left foot transfer data presumably equalizes the effect of the bodily location of the 'transfer' hand or foot relative to the hand or foot given the previous training, since one of the three groups in each four (R.H., L.H., R.F., L.F. transfer) was preceded by practice trials with the opposite and symmetrical hand or foot, one by practice with the hand or foot on the same side, and one by an opposite and non-symmetrical hand or foot.[4]

Amount of transfer may be measured by dividing the difference between initial and final speed in the practice trials into the difference between initial speed in practice and transfer trials. This 'percentage of the time gain through practice saved on the first transfer trial' is, in the present instance: right hand, 78 percent, left hand, 86 percent, right foot, 74 percent, left foot, 74 percent. The value of such a method of measurement is of course limited by the wide range of individual differences in the first practice trial.

Inspection of Table I might lead to the conclusion that transfer from hand to foot is greater than transfer from foot to hand. The absolute differences between practice and transfer records for the right and left foot is noticeably greater than the corresponding differences for the right hand, or for the left hand after the first trial. The superficial nature of such a distinction appears when we note that by the same criterion transfer from foot to foot is greater than transfer from hand to hand. In part at least the foot to hand seems less than the hand to foot transfer because the feet have more to learn and learn more slowly than the hands. It is an absolute difference, whereas amount of transfer is only relatively significant: *i.e.*, with respect to the amount learned in the practice trials. We have seen that the percentage of transfer on the first trial is 74 percent for either foot and 78 and 86 percent for the right and left hand respectively. Here the advantage is with the hands. On the contrary, a comparison of the last five practice and the last five transfer trials shows a slight superiority of foot over hand in amount of transfer. In neither case is the difference large enough to admit a definite conclusion.

The results of our former work in the field of cross-education have indicated that the transfer depends in part upon the relative (bodily) location of the practice and transfer muscle groups. In the present investigation conditions were arranged, particularly in equating the groups, with the aim of finding whether these results found for mirror-tracing hold for other kinds of material. In general emphasis was placed on equality in the last ten practice trials, but a fair measure of likeness was also secured on the first few trials, as may be seen from the averages in Table I.

To find the relative transfer to opposite and symmetrical, same side, and opposite and unsymmetrical muscle groups the records in Table I were arranged as below:

Practice	Transfer		
	Opposite and Symmetrical	Same Side	Opposite and Unsymmetrical
R.H.....	I L.H.	II R.F.	III L.F.
L.H.....	VII R.H.	VIII L.F.	IX R.F.
R.F.....	X L.F.	XI R.H.	XII L.H.
L.F.....	IV R.F.	V L.H.	VI R.H.

The Roman numerals indicate groups and correspond to the notation in Table I. Groups I, IV, VII, and X had transfer trials with muscle groups opposite and symmetrical to the hand or foot practiced. Averages for these four groups are represented by the heavy lines in Fig. 2. (Only the first ten of the practice trials are plotted.) Groups II, V, VIII, and XI, with whom the practiced hand or foot was on the same side of the body as the transfer hand or foot, are indicated in Fig. 2 by dotted lines. In Groups III, VI, IX, and XII the practice trials were followed by transfer trials with a hand or foot on the opposite side of the body and not in a symmetrical relation to the hand or foot practiced. The averages of the combined records of the last-named groups appear as light lines in Fig. 2. All curves in Fig. 2 are thus derived from averages of a right hand, left hand, right foot, and left foot record, and right-left and hand-foot differences should be equal in each.

Before averaging the data from the four groups represented by each curve in Fig. 2, the advisability of weighting the hand records was considered. It was evident, however, that no one method of weighting would be satisfactory, since hand-foot differences were not of the same order at the beginning and end of the practice trials. As I also found that various methods of weighting had little effect on the relative amount of transfer, I decided to average the scores as they appear in Table I.

A comparison of the upper lines in Fig. 2 shows no differences of importance between the practice curves. The lower lines indicate transfer (in general) from greatest to least: opposite and symmetrical (heavy lines), same side (dotted lines), opposite and unsymmetrical (light lines). The superiority of 'opposite and symmetrical' over 'same side,' however, only holds for the first four trials. From the fifth to the tenth trials the heavy and dotted transfer curves cross and recross. Apart from the last-mentioned discrepancy, the results of the present investigation support the conclusions from the two earlier experiments of the author. Computed by the method given above, the percentage of time saved on the first transfer trial is: opposite and symmetrical, 90 percent, same side, 80 percent, opposite and unsymmetrical, 63 percent. These are roughly comparable with percentages computed by a like method for transfer in mirror-tracing the star-shaped maze.

In regard to the duration of the transfer effect, inspection of Fig. 3 reveals that at the end of ten trials each of the transfer curves is appreciably lower than the practice curves for the same subjects. The transfer from twenty practice trials evidently persists for at least ten transfer trials. The trend of the curves suggests that for the 'opposite and symmetrical' and 'same side' groups the transfer would continue to influence the learning for twenty transfer trials. That is, the transfer is in part a permanent contribution to the efficiency of the unpracticed hand or foot. Indications of a similar nature have appeared in the author's experiments in mirror-tracing.

SUMMARY

One hundred and twenty subjects practiced tracing an irregular maze pattern without visual aid twenty trials with one hand or foot, and three minutes later ten trials with another hand or foot. Of the one hundred and twenty, thirty subjects had the initial training with the right hand, thirty with the left hand, thirty with the right foot, and thirty with the left foot. Ten subjects in each thirty had transfer trials with one of the other three limbs. All combinations of hand and foot practice and transfer trials were thus used.

The results in the main support those of the two earlier experiments in this series. The hand-foot differences were much greater in the practice series of the present experiment, however, and individual variability higher except with the right hand, due to a tendency of blindfolded subjects to push persistently against one corner or retrace the path.

In regard to transfer, it was found that:

(1) The percentage of transfer to all muscle groups was about the same as after 100 trials mirror tracing.

(2) Transfer was least to the opposite and unsymmetrical hand or foot for ten transfer trials. In the first four transfer trials the transfer was greater to the opposite and symmetrical than to the same side; for the last six trials the two were about equal.

(3) At the end of ten transfer trials the 'opposite and symmetrical' and 'same side' transfer groups had attained a like speed to that reached after twenty practice trials.

(4) Measured in absolute units the feet had more gain from transfer than the hands. In proportion to amount learned in the practice trials, however, there was no significant difference between the transfer from foot to hand and hand to foot.

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DISCUSSION

HOW DO WE SEE IN THE BLIND SPOT?

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Progress in science is made when investigators in a given field advance beyond the facts established by previous workers in that field. In two articles [1] published since my work on 'The effects of direct stimulation of the blind-spot' [2] we find a reversion to theories which previous investigations, including my own, had shown to be untenable, not to mention their inherent absurdity as soon as they are carefully examined. The unsuspecting reader of these articles is told that certain 'crucial' tests of vision in the blind spot are new whereas they had already been reported by Feinberg [3] and myself. Observations based upon hurried and obviously poorly controlled experimental conditions favoring contrast, totalizing, and irradiation theories of vision in the blind spot are presented while contrary evidence is dismissed with the *argumentum ad hominem* that I did not conduct my experiments as my report explicitly states. There is a studied disregard or real lack of knowledge of the work of many investigators whose results do not fit into the non-sensitive disc theories of the blind spot. Indeed, these writers go so far as to assert that a sensitive disc theory is contrary to configurational principles although a glance at the articles of Stern,[4] Feinberg,[5] and Koffka [6] is sufficient to convince anyone that these writers reject

[1] H. R. DeSilva and A. Weber, The responsiveness of the blind spot, this JOURNAL, 1932, **15**, 399–415 and C. R. Garvey, Is the blind spot blind?, *ibid.*, 1933, **16**, 83–97.

[2] H. Helson, The effects of direct stimulation of the blind spot, *A. J. Psychol.*, 1929, **41**, 345–397.

[3] N. Feinberg, Experimentelle Untersuchungen über die Wahrnehmung im Gebiet des blinden Flecks, *Psychol. Forsch.*, 1926, **7**, 16–43.

[4] A. Stern, Die Wahrnehmung von Bewegungen in der Gegend des blinden Flecks, *Psychol. Forsch.*, 1926, **7**, 1–15.

[5] Feinberg, *op. cit.*

[6] The studies by Stern and Feinberg were published under the direction of Koffka so he must have approved their findings; he has also published an article, The perception of movement in the region of the blind spot, *Brit. J. Psychol.*, 1924, **14**, 269–273. In this article he concludes, *contra* DeSilva and Weber and Garvey: "The blind spot is not absolutely blind, but merely highly insensitive to light-stimulation . . . ," p. 273. Garvey's statement that "DeSilva's is a Gestalt theory while Helson's is thoroughly mechanistic . . . which the Gestalt psychologists condemn" may be compared with the quotation just given from Koffka.

totalizing and theories which require that adjacent retinal elements be stimulated in order to see in the blind spot.

In my review of the work done in the blind spot I pointed out again and again that the unsettled state of knowledge about the real facts springs from the difficulty in observing in this region, and I showed what great differences slight, often unknown changes in conditions made in what is observed. Furthermore, the common practise of writers on this subject to neglect evidence contrary to their theories and to base dogmatic generalizations upon their own, restricted observations was pointed out also. Such a state of affairs, I said, required subsequent investigators to be cautious in generalizing and careful in experimenting.[7] There was therefore little excuse for burdening a literature already full of contradictory statements with more hasty observations and generalizations which do not stand up under more careful experimental control. The failure to find positive evidence in favor of a sensitive disc theory of vision in the blind spot may mean that the blind spot is absolutely blind or it may mean that such evidence is hard to find. But just as the difficulty, and often the impossibility, of observing the blue arcs or the six or eight phases of the visual after-image are no arguments against their existence, so the difficulty in obtaining positive evidence for a sensitive disc is no argument against its existence. It requires no special pains to get evidence in favor of the non-sensitive disc theories but it does require more than lackadaisical, routine experimental procedure to duplicate the results reported by those who have found evidence in support of the sensitive disc theory.

The ways of critics are indeed often strange. While refusing to accept the validity of observations made by individuals in my experiments, they accept their observations either when they find them acceptable or when these individuals served as their subjects.[8]

[7] See especially my 'Conclusions from the historical survey,' *op. cit.*, p. 363. A similar state of affairs exists in other difficult fields. After I had written the above I came across the following in Gelb's discussion of the disagreements among investigators regarding color constancy: "Slight changes in outer experimental conditions as well as changes in inner attitude can cause effects in observation which differ more or less from the results observed by others. In such cases *one must beware of generalizing his own results as well as denying the findings of others . . .*" (A free translation, italics mine). *Handbuch d. norm. u. pathol. Physiol.*, XII/1, *Photoreceptoren*, p. 600 (Berlin, 1929).

[8] Three of DeSilva and Weber's subjects had previously observed for me; two of Garvey's subjects had also observed in my experiments. Garvey's whole article is based upon the results of a *comparison* between two stimuli and he lists me as an observer for himself. However, he gives only one protocol as coming from me. This

This selection of material that fits with one's theory was justified on the charge that my observers were working with knowledge when they were supposed to be working in ignorance of the stimulating conditions. I need hardly point out that such a charge is wholly unfounded and unsupported by any evidence and is an indictment of the subjects in my experiments, three of them of professorial rank. My critics had overlooked the fact that other investigators, notably Feinberg, had reported findings unexplainable by traditional theories. Are we to assume that all investigators who find evidence in favor of the sensitive disc theory are not to be trusted? What is to be the answer when I present evidence given by one of my critics in favor of the sensitive disc theory, given when he acted as subject in some of my experiments, and hitherto unpublished?

I have postponed an answer to DeSilva and Weber's and Garvey's articles until further observations could be made either in my own laboratory by another investigator working in entire independence, or by a worker in some other laboratory. Such observations have now been made by my student, Miss Virginia Balough, and will be discussed in a later article. In as brief space as possible I wish to point out the untenability of my critics' position and to present some crucial observations made by one of them at a time when he had not formulated his theory of vision in the blind spot.

1. The first assumption upon which practically all of my critics' objections rest and which they seem to believe represents an inescapable fact of observation in the blind spot, but which has been found to be untrue by numerous investigators, is that the blind spot is filled in by some sort of totalizing process whenever we fixate a homogeneous surface. While it is true that naive observers do fill in the region of the blind spot, a slight amount of practise enables every subject with whom I have come in contact to see the blind spot as a break in the visual field. It is even possible to see a break in dotted, meshed and the various other kinds of fields usually used to

does not concern his two stimuli, but only one of them, so he apparently failed to use me as an observer in any *bona fide* sense in his experiments. He does state that only five of his six observers completed the series. If I did not complete the series why does he list me as an observer in his crucial experiments? If I did complete them, why does he not give my results along with the rest? It is unfortunate that I cannot, or at least will not, reproduce any of the comments of the individuals who served in both my critics' and my experiments regarding the conduct of the several sets of experiments. Suffice it to say here that anyone who performs a careful, conscientious piece of work in the blind spot with a real desire to get positive findings will be able to assess the investigations which I am criticizing in a fashion suitable to such work.

show the filling-in of the blind spot. Totalizing does not oc[cur] trained subjects. And after subjects have been trained to see the break in the field where the blind spot occurs, lack of practise for some time may necessitate fresh practise in order to observe 'analytically' again, as I can testify from my own experience.

All of my critics' reports of filling-in rest upon this fact: either their subjects were not given the training necessary to observe what is in the blind spot region, or conditions were so unfavorable to analytical observation that it was impossible for them to make the necessary discriminations. Later I shall show that even under their conditions, unfavorable as they were, the break in the field can be seen by subjects trained to do so. Thus if two rectangles of light are exposed on the edges of the blind spot, even projecting some distance in, naive subjects will report complete rectangle through the blind spot but with a slight amount of practise they report the dark center showing completion does not occur on the sensory level.

What are the facts regarding the totalizing process so far as other investigators are concerned, since it might be argued that I am a biassed investigator? As stated in my section on *Visibility of optic discs in the field of vision*,[9] Purkinje, Aubert, Helmholtz, Charpentier, Köllner, and Brückner have all observed the optic discs as differentiations within otherwise homogeneous fields. For the sake of my critics who seem unacquainted both with the literature and my account of it I repeat Köllner's words showing how simply it may be done: "one fixates both eyes upon a gray screen in a room of moderate or low illumination and both discs will appear as dark rings and disappear; at this point close one eye suddenly and both blind spots will be visible . . . ." [10] Brückner substantiates this method in his report that the discs may be seen by fixating light, dark or colored surfaces.[11]

What shall we say of the competence of critics who state, in the face of excellent authority to the contrary: "Even when we close one of our eyes and look upon a uniform surface we do not notice any difference between that part of the surface which stimulates the blind spot and the rest of the visual field; the total field is homogeneous." [12] We can only say one does not notice any difference under conditions of unpractised, hasty observations and when one does not wish to do so.

[9] *Op. cit.*, pp. 352–353.

[10] H. Köllner, Der blinde Fleck im binokularen Sehfelde, *Arch. f. Augenhk.*, 1912, 71, 306–313.

[11] A. Brückner, Ueber die Sichtbarkeit des blinden Fleckes, *Arch. f. d. ges. Physiol.*, 1913, 136, 615–620.

[12] *Op. cit.*, p. 399.

lva and Weber feel they are on sure ground in postulating a totalizing mechanism for the blind spot similar to, if not identical with, the totalizing reported by Fuchs and Poppelreuter [13] with hemianopsic subjects. Had they submitted this hypothesis to experimental test as I did some years ago they would not have found it so acceptable. I attempted to duplicate the results of Fuchs and Poppelreuter using the blind spot as the non-functional area. Solid and outline figures were exposed for intervals ranging from 1/50 to several seconds. Various parts of the figures were allowed to fall in the blind spot. Totalizing occurred so seldom in the blind spot as to make the theory of the German investigators absolutely untenable under our conditions. I did not rush into print with my failure to duplicate their results because of the difference in experimental, and possibly other, conditions.

We find that by direct test and under conditions of analytical observation totalizing does not occur. It does not occur under our conditions when figures are allowed to project into the blind spot and does not occur when homogeneous or broken fields are viewed by trained observers. Generalizations to the effect that it is an universal characteristic of blind spot functioning are based upon unpractised observation.

2. But totalizing is not enough in itself to explain what is seen in the blind spot for two other mechanisms are invoked to explain facts which it cannot account for. The second mechanism at work in the blind spot, we are told is that of contrast. According to DeSilva and Weber the blind spot is insensitive, blind. We see, so they say, in the blind spot when a light *in* the blind spot contrasts with the surrounding dark field. Here we have an admission that the light inside the blind spot does not always irradiate into the field outside for it is *dark*, a point we shall come back to later. The absurdity of the contrast theory appears the moment we reflect upon what it means in their terms: a region insensitive to light is supposed to be lit up by a light falling upon it, whereupon it appears light in contrast with the dark field around it! If the blind spot is insensitive, how can it be lighted by a light falling in it?

If my critics had consulted the literature they would have found their contrast theory exploded long ago. Brückner [14] wrote: "If one looks at a dark background the disc should appear light or gray

[13] W. Fuchs, Untersuchungen über das Sehen der Hemianopiker und Hemiamblyopiker, *Z. f. Psychol.*, 1920, **84**, 67ff., and **86**, 1ff. W. Poppelreuter, *Die Störungen der niederen und höheren Sehleistungen*, Leipzig, 1917.

[14] Brückner, *op. cit.*

according to the law of contrast" but Brückner found that it looked "a deeper black than the background until the general illumination of the room was decreased." He therefore rejects contrast as an explanation in such cases which are similar to those for which DeSilva and Weber invoke it. And when non-contrasting colors are seen, one within and the other outside the blind spot, obviously neither contrast nor totalizing can be responsible for the one mechanism can explain only contrasting colors and the other only similar colors in the two regions.

3. We come to the third assumption to explain vision in the blind spot, namely irradiation. The ambiguity of this term, pointed out in my paper, is not dispelled by my opponents in their use of it. By it they seem to mean the stimulation of adjacent retinal elements when light falls on the blind spot. In dismissing my evidence against this theory with a charge of incompetence these critics overlooked the fact that Feinberg had rejected the theory on the basis of observations similar to mine in a different laboratory and with different subjects. As Feinberg and I have stated, when the intensity of the stimulus in the blind spot is adjusted so that it does not reach the edges as seen, the irradiation theory requires that a stimulus having a subliminal effect on adjacent retinal elements (since it is not seen outside the blind spot) should be observed above the threshold within the blind spot.

One observation made by Miss Balough, and quoted here with her permission, is crucial for the irradiation theory and is, so far as I am aware, a new observation. A solid circle of light was exposed on the right edge of the blind spot so that its center fell on the center of the 'in' and 'out' determinations of the blind spot, leaving about equal areas inside and outside the blind spot. Observer Bs. reported: "Small yellowish, definite light at right, bluish haze at left." C., another observer, said: "Semi-circle on the right and bluish fog at the left." Repeated observations with these *O*s and one other subject on following days elicited reports showing that outside the blind spot the stimulus had a definite shape, semi-circle, and was yellowish, while inside it lacked shape, foggy, and was bluish. We find here the same stimulus giving rise to two totally different impressions simultaneously. Since stimuli within the blind spot are bluish at the threshold (as well as outside, often, as Miss Balough has now found) we have here the same stimulus above the threshold outside the blind spot and near it inside. Obviously the same retinal elements cannot mediate a supraliminal and a

liminal stimulus simultaneously, cannot mediate yellow and blue simultaneously, cannot mediate definite form with a definite localization and a foggy haze with different localization and lacking form, simultaneously. Irradiation requires a given set of receptors to have two place coefficients *simultaneously*. While *changes* in place coefficients are easy to demonstrate both in vision and on the skin it has yet to be proved that different place coefficients may be mediated by one set of receptors at any given time.

It is hardly necessary to repeat the arguments against the irradiation theory which I made in my former article nor the evidence upon which they were based. Miss Balough's observations cannot be dismissed with the charge that the experimenter somehow forced them and I wish to quote some observations of Garvey when he acted as subject for me which he will not be able to dismiss as easily as he did those of the other subjects who took part in my experiments since there has never been any question in either his or my mind of their *bona fide* character.

Garvey believes he finds support for the irradiation theory by referring to observations "When Helson presented his subjects with two squares one above the other, the description was of an upright rectangle."[15] But this description, apparently favoring the irradiation theory, was not given by all subjects and since Garvey does not accept evidence from subjects in my experiments contrary to his theory, let us see what he himself reported on this question. On April 20, 1927, I exposed on the top edge of Garvey's blind spot a solid, 2 cm sq. blue stimulus and in the center of the blind spot, about 16 cm distant, a 2 cm sq. yellow stimulus. Garvey reported: "I saw a large diffuse yellow light which seemed to be round and about 10–12 cm, gradually grading off to less and less light, a yellowish-white. Above this, in place where top square of light has been was a square spot of light that seemed to be bluish-white. THE TWO WERE NOT CONNECTED" (The whole passage in quotes is Garvey's).

Lest the above observation be taken to have been an accident I repeated similar tests. Here are some of them. I exposed three squares of light, one on the top edge, one on the bottom edge, and one in the center of the blind spot. Garvey reported: "Saw two squares, one above, one below and a sort of diffuse light in the middle between the other two—vague, scattered. Hard to tell if it was square or vertical." In this protocol the stimulus in the center seems to have a hint of formedness which I found most subjects were able to observe.

[15] *Op. cit.*, p. 94.

To test the irradiation theory further, I exposed a green square in the center and a blue square at the top edge of the blind spot. Garvey saw: "Bluish purple square above and in the middle position I saw a very faint radiation of green, very faint." Again no mention of any meeting of the outer and inner stimuli. To make sure, the following arrangement was used and Garvey's report contains evidence as much in favor of a sensitive disc theory as one could ask: 11 solid circles (or discs) about 2 cm in diameter arranged to form a ring around the blind spot were illuminated by an ordinary lamp giving a yellowish-white color while within the blind spot a green circle about 2 cm in diameter was exposed. Garvey's protocol reads: "I saw a big circle of yellowish-white and inside the dots is illuminated with green—a uniform green illumination which in some sides of the circle does not quite extend to the white dots—that is, a little rim of dark space."

Garvey may be able to explain his observations by the irradiation theory but I fail to see how by any stretch of the imagination *yellowish-white dots* can, by irradiating into the blind spot, give rise to a *uniform green* in the center, leaving *a little dark space in some sides*. We might also ask DeSilva and Weber to explain how totalizing or contrast will give green from yellowish-white. Finally, we would like to know how the ring of dots can keep their form and still irradiate into the blind spot. Too much is demanded of irradiation and totalizing when we are asked to believe that identical receptors can mediate forms outside the blind spot and non-formed or differently formed perceptions at the same time inside the blind spot, and to mediate one color outside the blind spot and a different color inside the blind spot.

Finally, it should be remembered that Feinberg had done Garvey's crucial experiment, even before I did, and came out with results similar to mine against the irradiation theory.[16] With careful control of conditions and practised subjects it was possible to expose a ring of light extending well into the blind spot, not merely around its edges as in Garvey's and my easier tests, and the dark center will still be seen contrary to the totalizing and irradiation theories.[17]

[16] Feinberg, *op. cit.*, p. 40: "Unter unseren Versuchsbedingungen wurde *in der Regel* ein *aussen am Rande* des bl. Fl.-Gebiets exponierter heller Ring als Ring gesehen, mit innen schwarzem Gebiet." (Italics are in the original.) Feinberg stresses the fact that *as a rule* the dark center was reported, supporting my contention that practise is necessary.

[17] Feinberg reports this fact in the rest of the paragraph from which the sentence quoted in footnote 16 is a part. Miss Balough repeated Garvey's 'crucial' tests and

No better summary to these remarks can be framed than an attempt to bring together the three mechanisms postulated by DeSilva and Weber (and apparently accepted by Garvey) since nowhere in their article do they try to show us how and when each of these explanations is supposed to hold. If the contrast theory holds, then my opponents admit irradiation is often absent for here they claim *the blind spot is light while the rest of the field is dark*. But we have seen that on their assumption of an insensitive disc the blind spot cannot be lit up and thus the contrast theory is found to contain an inner contradiction and is therefore nonsense. If we suppose irradiation and totalizing to be at work, then the adjacent field is stimulated and the surrounding field should be lit up and the blind spot of the same color as the rest of the field. But numerous observations, *e.g.*, Garvey's for me, show different colors may be seen simultaneously in the blind spot and outside. If contrast is at work, when the rest of the field is lit up then the blind spot should be dark but this works against irradiation and totalizing. Since the phenomena inside are different in color and form from those outside, neither contrast (when the difference is non-contrasting), nor irradiation, nor totalizing will explain how we see in the blind spot. We thus find the non-sensitive disc theories at variance with each other and with the observed facts. We are forced to some form of sensitive disc theory such as I proposed in my original article and which I believe other, impartial investigations will confirm.

I have lately succeeded in interesting a number of individuals in this problem from the point of view of action currents. The production of action currents in the optic nerve fibers when the optic disc is stimulated by light, the rest of the retina being deleted, would be objective evidence in support of my theory. Such evidence must be forthcoming sooner or later to tally with the observations made in the psychological laboratories. I have been informed by one prominent worker in action currents that nerves

found her subjects were able to distinguish between his two figures in nearly 100 percent of the exposures. In fact, we are unable to understand why Garvey's subjects could not identify the ring figure (*vide* Garvey, p. 86) because of the tell-tale black strips that he used to hold the center in place! Miss Balough's subjects saw these at once and she had to eliminate them by fastening the central portion to the screen with soft wax so that the only difference between the figures should be truly what Garvey intended. Since it is an established fact that subjects can observe the dark central field when only the periphery of the blind spot is stimulated with a light of moderate intensity, why did not Garvey give his subjects some practise before attempting his 'crucial' tests? It is obvious that the problem is not to see how little subjects can report, but how much they can discriminate when conditions are nevertheless proof against artifacts.

treated with eosin will give rise to action currents when stimulated by light. May there not be in the human, living optic disc some substance, which, when acted upon by light, is capable of stimulating the nerves, giving rise to the phenomena some of us have described? If this substance is a chemical substance more or less dispersed throughout the disc the necessity for postulating end-organs in it will be unnecessary.[18] At least the sensitive disc hypothesis has been and will be productive of further investigation. Thus knowledge is advanced.

[18] The question of eccentric projection still remains on this hypothesis and is a difficult one for any hypothesis, as DeSilva and Weber admit for their theories. It might well be true that so long as the ordinary nerve endings are present and in connection with their normal receptors that stimulation along the trunk gives rise to different localization. If there is nothing within the disc to account for all the facts then, as Feinberg has emphasized, some form of theory very different from all those yet proposed will have to be invented. To me the sensitive disc theory seems to be the simplest in the end.

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